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JOINT CHINOOK TECHNICAL COMMITTEE

SPECIAL REPORT
INVESTIGATION OF MATURATION-RATE ESTIMATION MODELS AND THEIR INFLUENCE ON PSC CHINOOK MODEL ABUNDANCE INDICES

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List of Acronyms and Abbreviations

AABM	Aggregate Abundance Based Management
AC	Allowable Catch
AKS	Chinook Model stock - SE Alaska stocks
AEQ	Adult Equivalent
AUC	Area-Under-the-Curve
AWG	CTC Analytical Working Group
BON	Chinook Model stock - Bonneville
BTR	Base Terminal Run
BY	Brood Year
BYER	brood year exploitation rate
CAS	cohort analysis database
CI	Confidence Interval
CLB	Calibration
CNR	Chinook Non-retention
CPUE	Catch per unit effort
CR	Columbia River
CTC	Chinook Technical Committee
CV	Coefficient of Variation
CWF	Chinook Model stock - Cowlitz Tule
CWT	Coded Wire Tag
CY	Calendar Year
ESC	Escapement
ETS	Exponential Smoothing Model (Error, Trend, Seasonal)
ERA	Exploitation Rate Analysis
EV	Environmental Variable scalar
FI	Fishery Index
FR	Fraser River
FRL	Chinook Model stock - Fraser Late
GS	Strait of Georgia
GSH	Chinook Model stock – strait of Georgia hatchery
HOR	Hatchery Origin Returns
IM	Incidental Mortality
ISBM	Individual Stock Based Management
LFR	Lower Fraser river
LGS	Lower Strait of Georgia
LRW	Chinook Model stock – Lewis River Wild
MATAEQ	Mature run equivalent, also a Chinook model input file
MR	Maturation Rate
MRE	Mature-Run Equivalent
MSE	Mean squared error
MSF	Mark Selective Fishery
MSH	Maximum Sustainable Harvest
MSY	Maximum Sustainable Yield for a stock, in adult equivalents
NA	Not Available
NC	North Coastal
NBC	Northern British Columbia (Dixon Entrance to Kitimat including Haida Gwaii)
NPS	North Puget Sound
NPS-S/F	North Puget Sound Summer/Fall Chinook stock
NR	Not Representative
ORC	Chinook Model stock – northern Oregon Coast aggregate
PNV	Proportion non-vulnerable
PS	Puget Sound
PSC	Pacific Salmon Commission
PST	Pacific Salmon Treaty
RBH	Chinook Model stock - Robertson Creek Hatchery
RBT	Chinook Model stock - Robertson Creek
RER	Recovery Exploitation Rate
ROM	Ratio of means
SA	Stock Aggregates
SE	Standard Error
SEAK	Southeast Alaska Cape Suckling to Dixon Entrance
SMSY	Escapement producing MSY
SPR	Chinook Model stock – South Puget Sound Recovery
SPS	South Puget Sound
SPFI	Stratified Proportional Index
TAC	Total Allowable Catch
TR	Terminal Run
UFR	Upper Fraser River
UGS	Upper Strait of Georgia
UMT	Upper Management Threshold
UMSY	Exploitation Rate at MSY
URB	Chinook Model stock - Columbia Upriver Bright
WAC	Washington Coast
WCVI	West Coast Vancouver Island excluding Area 20
WSH	Chinook Model stock – Willamette Spring
YA	Year Average

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Executive Summary

During the October 2015 Pacific Salmon Commission (PSC) Executive Session held in Sooyemouth, Washington the following assignment was given to the Chinook Technical Committee (CTC) by the PSC Commissioners:

The PSC Chinook Model performance over the last several years has been highly variable based on the wide swings in estimated abundance as expressed within the model calibration abundance indices. The amount of technical debate that has ensued over the last 8 months has been cause for the CTC and AABM to request of the Commission instruction on several aspects of technical work moving forward (Memo to Commissioners from CTC dated September 4, 2015). There were two elements that were transmitted relative to the US Section meeting on June 10, 2015: one was timeliness of release of the preseason abundance index and the other was stability of the model calibration results. There are also several work products that are of immediate and longer term value for the Commission that we request you complete as best possible within the prescribed timelines as depicted below. We have heard discussion and received reasonable correspondence specific to the timing element, however the model stability element has not been adequately addressed.

The Commission is requesting that the AABM embark on investigating both the maturation rates and environmental variables to update and document the analyses performed in 2012 with the last two years of data. The objective is to provide for improved preseason and postseason abundance indices to be generated for the 2016 season and postseason AI's for both the 2014 and 2015 seasons. We understand it is important to start this work soon to inform the current year calibration, and suggest the work completed by December 31, 2015 and no later than January 1, 2016 so that we can be assured that a preseason AI can be generated, evaluated and released for fishery planning purposes.

The CTC AABM updated the *2012* maturation-rate (MR) and environmental-variable (EV) analysis, which used results from the *2004* through *2012* calibrations of the PSC Coast-Wide Chinook Model with results from the *2013* and *2014* calibrations (see TCCHINOOK(14)-03 Y 1, section 3.1.4 for a description of the original work). The new analyses were based on pairings of MR estimates with the EV of the most recently completed brood. This decision was made because the *2012* analysis showed that the estimation of the age-specific MRs used to represent a stock's incomplete brood years had a much greater influence on AIs compared to the EV. In order to determine if the discrepancy between the preseason and post-season Chinook Model AIs could be reduced from the 5-year average (YA) model chosen in the *2012* analysis, the investigation was expanded to include more MR estimates. In addition to the long-term average (starting in 1979), stock- and age-specific MR averages ranging from 3 to 12 years from recent completed broods were evaluated. An approach to estimating the MRs for incomplete broods based on a time series exponential smoothing model (ETS) was also explored as a potential alternative to the method based on a simple average of a specified number of completed broods.

Model calibration results based on the above MR estimates were evaluated using four statistics (squared error, percent error, median error and absolute scaled error) which quantify the magnitude and direction of the discrepancy between two AIs. The statistics were calculated for the discrepancy observed between (1) the preseason AI for each AABM fishery and the first post-season AI, (2) the preseason AI and an average of the post-season AIs for that same year from calibrations completed three or more years after that preseason, and (3) the first post-season AI and the average AI from calibrations completed three or more years after that preseason calibration. Although the three types of discrepancies above were investigated, the one which carried the most weight in our findings was the discrepancy between the preseason AI and the first postseason AI due to the fact that the measures of compliance in the AABM fisheries are the allowable catches associated with the first postseason AIs.

Eleven (or modified) of the error statistics were then compared to those which of the MR estimation models resulted in the greatest reduction in the discrepancy between the observed from the Chinook Model calibrations. These results are documented in this report as well as other cross-over results considered relevant. The main findings of the MR-DI investigation are:

- Based on the composite mean squared error statistic (MSE), the 6-year average model (6YA) emerged as the estimation model that most reduced the discrepancy between the preseason and first post-season AI across Chinook Model calibrations and SHIMA fisheries (Table 1);
- The sensitivity of the above conclusion to the number of catch/tag calibrations was examined and the 6 CN spawn emerged as the best overall estimation model based on the composite MSE statistic (Table 2);
- The 6YA, 3 year average model (3YA), and time series model (ETS) most reduced the discrepancy between the preseason and first postseason AI across Chinook Model calibrations for the SHIMA, WSC, and WCVI SHIMA fisheries respectively. However, further work is warranted since the difference in performance of a number of the models was small;
- The model used to estimate the MRs noticeably affected the time series of preseason and first post-season AIs for each SHIMA fishery, but the overall effect on the magnitude and direction of errors compared to the original calibration results was relatively small;
- An analysis using the North Oregon Coast stock aggregate demonstrated a method to estimate naturally produced stock aggregate MRs by extrapolation from hatchery CWT calibration stock exploitation analysis, and the hatchery CWT calibration stock MRs. Differences were subsequently, from the naturally produced stock aggregate MRs.

The CTC recommends the utilization of the 6YA for the MRs and 1 year DI as the basis for estimating the stock- and age-specific MRs for the annual Chinook Model calibration (Table 1), and further recommends that the MR and DI analysis is repeated in subsequent years so that perceived potential improvements can be realized.

Table 1: When repeated error between the processor and the processor of percentage x. Lose left. Each left model depicts how the assumptions surround incomplete known users can installed, including the x- year- average (e.g., AAA). Image term coverage (CTE) or. Our exponential smoothing (ETS). The composite MAE matrix in the cumulative of the MAE service the x histories. The scenario most environment MAE is highlighted in darker shading and the second-can scenario in highlighted lighter shading.

	Scenario	ΔAIC	ΔBIC	ΔAICc	Composite
ARIMA	ETS	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0)	0.0 (0.0)
	SVM	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	THE	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	ETS	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	RNN	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	ARIMA	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	ETS	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	LTE	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	ETS	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Table 2: The true MAE estimation model in response to the number of calculations computed in MAE calculations. The earliest calculation year is MAE in all cases. The composite is based on the sum of MAE values across histories. Abbreviations used in Table 1 are described in those used in this table as well.

Model Family	# Coefficients	ΔAIC	ΔBIC	ΔAICc	Composite
ARIMA	3	0.0	0.0	0.0	0.0
ARIMA	5	0.0	0.0	0.0	0.0
ARIMA	8	0.0	0.0, 0.0	0.0	0.0
ARIMA	7	0.0	0.0	0.0	0.0
ARIMA	9	0.0	0.0	0.0, 0.0	0.0
ARIMA	5	0.0	0.0	0.0	0.0

In conclusion, this investigation still shows that improved performance of the Ground Results, as measured by a reduction in the across calibration discrepancy between the processor and processor, enables thirteen the, could be achieved through use of MAE based on a MAE from completed through the same cause and age in the MAE MAE file. We and Core user's undertaken to determine why one particular MAE model performed better in a source than others.

[redacted]

5 [illegible]

5.1 [illegible]

$$[illegible] = \frac{[illegible]}{[illegible]} \cdot [illegible]$$

5.2 [illegible]

$$avgMatMix_{c,a} = \frac{1}{n = \sum_{y=(CY-n+1)}^{CY} I(valid_{c,a,y} = 1)} \sum_{\substack{y=CY \\ down}}^{CY-n+1} I(MatMix_{c,a,y} | valid_{c,a,y} = 1)$$

and

$$avgMEQ_{c,a} = \frac{1}{n = \sum_{y=(CY-n+1)}^{CY} I(valid_{c,a,y} = 1)} \sum_{\substack{y=CY \\ down}}^{CY-n+1} I(MEQ_{c,a,y} | valid_{c,a,y} = 1)$$

where $avgMatMix_{c,a}$ is the average MM for a particular stock and age, $MatMix_{c,a,y}$ is the MM for a particular stock and age given that the brood is valid (i.e. $valid = 1$ and otherwise $MatMix_{c,a,y} = 0$), $avgMEQ_{c,a}$ is the average MEQ for a particular stock and age, $MEQ_{c,a,CY}$ is the MEQ factor for a particular stock and age given that the brood is valid (i.e. $valid = 1$ and otherwise $MEQ_{c,a,y} = 0$), CY denotes calendar year, c is stock, a is age class, $valid_{c,a,y}$ is a dummy variable that indicates whether a particular stock and age brood is valid or not (if the brood is valid, $valid_{c,a,y} = 1$ and $valid_{c,a,y} = 0$ otherwise), n is the number years to use in the average, y is an indexing variable, and $I(*)$ is an indicator function that when evaluated returns a value of 1 or 0. See Observed MM values in Appendix A for details on the stock-specific valid brood years.

2.3 Stock and Age-Specific Projections of Maturation Rates

2.3.1 Background

Explorations of time series of MMs have shown that: (1) there are different trends in the trajectories of various stocks; (2) these trends can differ among age classes for a given stock; and, (3) some stocks exhibit more variability in their MMs than others (see Appendix B). Stock- and age-specific projections of MMs might be more appropriate than the application of a naive model (e.g., most recent year, 2YA, 5YA, etc.) to all stocks and ages. Stock- and age-specific projections of MMs were produced with exponential smoothing (ETS) models and trend analysis. The former was applied to the last few years in the time series to address the effect of incomplete brood years whereas the latter was used to project MMs "one" year in the future. All analyses were based on calendar-year time series of MMs in the 2004-2018 MATAEQ files, which include data for Chinook Model stocks AKS, BON, CWF, GSH, LRW, ORC, RBH, RBT, SPR, UNB, MSH, and FIN. Although MMs are originally calculated at the brood year level, the application of statistical models such as the time series and trend analyses conducted herein can directly use calendar year data in a forecasting fashion.

2.3.2 Addressing the effect of incomplete broods on time series of calendar-year maturation rates in MATAEQ files

The exponential smoothing models (ETS) described herein are a general class of state space models for forecasting univariate time series (Caltper et al. 2010). The acronym ETS denotes the error (E), trend (T), and seasonal components (S) which can be used to describe the time series to be forecasted. The trend component represents the growth or the decline of the time series over an extended period of time. For time series defined at time intervals which are not fractions of a year (e.g., months), the seasonal

component is a pattern of change that repeats itself every number of years (i.e., a cycle). The error component captures irregular, short-term fluctuations present in the series, which cannot be attributed to the trend and seasonal components.

ETS models can be classified according to the nature of the error, trend and seasonal components of the underlying time series. The error (E) component can be either additive (A) or multiplicative (M). The trend (T) component can be additive (A), multiplicative (M) or inexistent (N). The trend (T) component can also be dampened additively (Ad) or multiplicatively (Md). The seasonal (S) component can be either additive (A), multiplicative (M) or inexistent (N).

Each particular combination of options for the error, trend and seasonal components of a time series gives rise to a specific ETS model. Since the possibilities for each component are Error = {A,M}, Trend = {N,A,Ad,M,Md} and Seasonal = {N,A,M}, in total there exist $2 \times 5 \times 3 = 30$ such ETS models. Components designated by the letter N are not present in the time series of interest. Components designated by the letter A are present and are combined with the other components via addition. Components designated by the letter M are present and are combined with the other components via multiplication.

For example, the ETS model ETS(AAN) has E(A), T(A) and S(N) structures, where E(A) stands for additive error, T(A) stands for additive trend and S(N) stands for inexistent seasonality. One can show that ETS(AAN) is Holt's linear model with additive errors according to the classification of methods described in Hyndman et al. (2002) and Hyndman et al. (2008).

The R (R version 3.2.3; R Core Team 2015) package *forecast* (Hyndman 2015) was used to implement exponential smoothing on time series of calendar-year Mits (and AEQs) for all stocks in the 2004-2014 MATAEQ files (see Appendix C). The application of the ETS for a given MATAEQ yearly file was applied to sequential subsets of time series M and starting with the subset not affected by incomplete brood years (usually $M_{s,a,i:z}^{t=i+a}$, where s is stock, a is age, t is time (i.e., calendar year), i is the start of the time series [1979 in all cases], and z is the "current" calendar year). Given an input time series, the projections were generated by applying the function *forecast()* directly to each of the time series $M_{s,a,i:z}^{t=i+a}$, $M_{s,a,i:z}^{t=i+a+1}$, $M_{s,a,i:z}^{t=i+a+2}$, $M_{s,a,i:z}^{t=i+a+3}$, and $M_{s,a,i:z}^{t=i+a+4}$ to sequentially populate projected stock- and age-specific data starting from the youngest age through the calendar year z as shown in Figure 2.1. This function selects an ETS model using the AIC, estimates the parameters, and generates forecasts. Although this function returns prediction intervals, only point forecasts were extracted from the forecast distribution. The methodology is fully automatic. The only required argument for *forecast()* is the time series. The ETS model is chosen automatically if not specified.

2.3.3 Projecting calendar-year maturation rates (and adult equivalents) in MATAEQ files using trend analysis

The evaluation of trends in Mits was based on the time series updated to the current calendar year through the aforementioned ETS projections (i.e., $M_{s,a,i:z}^{t=i+a}$; see Figure 2.1). The projection of Mits (and AEQs) for year $z+1$ was based on a state-space exponential growth model (Dennis et al. 2006)

parameterized through state-space restricted maximum likelihood (SSRML, Humbert et al. 2009), which produces rates of change estimates that are generally superior to those produced through maximum likelihood (Staples et al. 2004). This method assumes both observation error and process noise and therefore produces variances and confidence intervals that fully represent the annual variability associated to environmental stochasticity and sampling or observation error (Humber et al. 2009). Analyses were conducted using the R package *MASS* (Ripley 2015) with the selected time period for the characterization of trends starting in 1979 in all cases and ending in the calibration year represented by each of the original MATAEQ files. Although stock- and age-specific projections would be characterized by both long-term mean rate of change (μ) and corresponding 95% confidence intervals, only μ was reported. The value of μ can be positive or negative, indicating the direction and proportional change in MRs expected given the full extent of the time series, with $\mu = 0.00$ indicating equilibrium. Therefore projected MRs for year $z+1$ were computed as:

$$\hat{M}_{s,a,f=z+1} = M_{s,a,f=z} * \left(1 + \mu_{s,a}\right)$$

2.3.4 Constraints in projected values

Projected values of MRs and AEQs were constrained to the range 0 to 1. The application of the ETS-SSRML model to calendar-year MRs (and AEQs) showed only one case of a slightly negative ETS projected value for the first age for the ORC stock for year 2008, thus highlighting the need to constrain projections to abide by the biological scale in which these rates are expressed. A value of zero is a legitimate possibility in time series of MRs (and AEQs), as shown in the original 2008 ORC time series. In addition, the original time series of MRs for 2013 LRW also showed a value of zero for the first age but projections were positive in this case. Although there were no projected values of 1 or greater than 1 for either MRs or AEQs, a value of 1 is frequently a legitimate value for AEQs in the MATAEQ files. Other possible types of constraints such as constraining values to the observed range for individual time series were not included because the existence of trends in some time series is expected to produce projections that could be out of the range of the time series of observed values. The very essence of the time series and trend analysis methods is to identify patterns and trends, if present, and convey this information into the projected values.

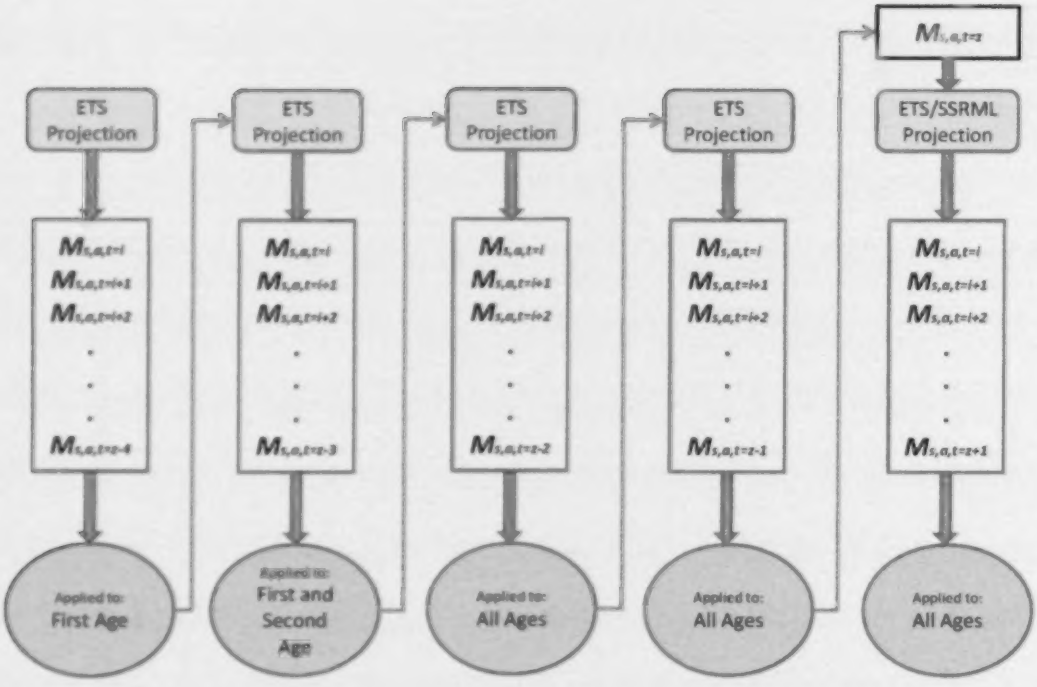

Figure 2.1. Schematic of model used to project stock- and age-specific calendar-year MRs. The methodology uses (1) exponential smoothing (ETS) to complete time series for years affected by incomplete brood years and project MRs for calendar year *z*, and (2) state-space restricted maximum likelihood (SSRML) trend analysis to project MRs for calendar year *z*+1.

Note: The method started with time series $M_{s,a,t=i}^{s,a,t=z-3}$ for the 2013 and 2014 MATAEQ files because there was an extra year of projection-free calendar-year MRs.

For convenience, the combination of ETS and SSRML models above described is simply referred to as ETS in the next sections, including figures and tables.

2.4 Differences between Maturation Rates for CWT Indicator Stocks and for Stock Aggregates

2.4.1 Background

In producing Abundance Indices (AIs) for pre-terminal marine fishing areas, the PSC Chinook Model fits to inputs of escapement (ESC) or terminal return (TR) of the various stock aggregates (SA) and to inputs of MRs for the CWT indicator stocks representing the SAs. Because of the importance of accurate

estimates and forecasts of TR, in this report the CTC-AWG investigates differences between preseason and postseason AIs over the period of years over which CWT indicator stock MRs are averaged to forecast MRs for incomplete broods. However, almost all CWT indicator stocks are hatchery populations and it is well established that hatchery populations generally exhibit earlier maturation and return by age than nearby natural populations. In contrast, the sum of TR by age for its component river populations best represents the SA and thus should provide for the best estimates of MRs.

2.4.2 Estimation of stock aggregate maturation rates by extrapolation from CWT indicator stock exploitation analysis

A method to estimate MRs for a SA using TRs summed across rivers in combination with CWT indicator stock exploitation analysis is demonstrated here. This demonstration example employs the Salmon River Hatchery (SRH) CWT indicator stock and the North Oregon Coast (NOC) SA, for which five BYs were randomly selected for this analysis. However, the method can be applied to any BY for any SA (or a subset of rivers of an SA) and its CWT indicator stock. Terms used in this demonstration are defined in Table 2.1.

Table 2.1. *Term definitions used in the CWT indicator and stock aggregate analysis.*

Term	Definition
TF	terminal fishing total mortality
ESC	spawning escapement
TR	terminal fishing total mortality plus spawning escapement (TF+ESC)
TRprop	the proportion of total TR of a specific age
PTF	pre-terminal fishery total mortality
CO	cohort size before PTF occurs
PTFR	pre-terminal fishery total mortality rate (PTF/CO)
MR	(TR/(CO-PTF))

For the SA, the TRs consist of the sum across NOC rivers of ESC apportioned by age based on spawner survey peak counts and carcass/scale sampling, plus a TF component reflecting the CWT indicator stock TF/ESC ratio

NOC TF = NOC ESC * (CWT TF/CWT ESC), by age

As done in the CTC's exploitation rate analysis and the PSC Chinook Model, we assume that exploitation of the CWT indicator stock reflects that of the SA

CWT stock PTFR = SA PTFR, by age

Estimates for the SA complimentary to those for the CWT indicator stock were derived using Coshak (the CWT cohort reconstruction program used by the CTC) backwards run reconstruction (exploitation analysis) methods, starting with age 6 since the age 7 cohort is approximately 0.

Finally, ratios for TRprop and MR between the CWT stock and the SA for each brood-year and age simplify comparisons

CWT stock TRprop/SA TRprop

and

CWT stock MR/SA MR

The computations are simple arithmetic, and below are calculations of CO, PTF, and MR for the SA 1992 brood-year (some small rounding error is present, see Results section for figures used). First, one estimates CO for the SA, assuming exploitation of the CWT indicator stock represents that of the SA:

CO age 7 ~ 0

CO age 6 = (CO age 7/0.9+TR age 6)/(1-PTF rate age 6) = (0+19,162)/(1-0.186) = 23,552

CO age 5 = (CO age 6/0.9+TR age 5)/(1-PTF rate age 5) = (23,552/0.9+54,009)/(1-0.275) = 110,514

CO age 4 = (CO age 5/0.9+TR age 4)/(1-PTF rate age 4) = (110,514/0.9+191,224)/(1-0.118) = 355,850

CO age 3 = (CO age 4/0.8+TR age 3)/(1-PTF rate age 3) = (355,850/0.8+37,893)/(1-0.049) = 507,338

CO age 2 = (CO age 3/0.7+TR age 2)/(1-PTF rate age 2) = (507,338/0.7+11,187)/(1-0.055) = 778,665

Next, one estimates PTF for the SA by applying CWT stock PTFR:

PTF age 6 = CO age 6*PTFR age 6 = 23,552*0.186 = 4,390

PTF age 5 = CO age 5*PTFR age 5 = 110,514*0.275 = 30,336

PTF age 4 = CO age 4*PTFR age 4 = 355,850*0.118 = 41,832

PTF age 3 = CO age 3*PTFR age 3 = 507,338*0.049 = 24,632

PTF age 2 = CO age 2*PTFR age 2 = 778,665*0.055 = 42,710

One can then estimate MRs for the SA using the estimates above:

MR age 6 = TR age 6/(CO age 6-PTF age 6) = 19,162/(23,552-4,390) = 1.000

MR age 5 = TR age 5/(CO age 5-PTF age 5) = 54,009/(110,514-30,336) = 0.674

MR age 4 = TR age 4/(CO age 4-PTF age 4) = 191,224/(355,850-341,832) = 0.571

MR age 3 = TR age 3/(CO age 3-PTF age 3) = 37,893/(507,338-24,632) = 0.073

MR age 2 = TR age 2/(CO age 2-PTF age 2) = 11,187/(778,665-42,710) = 0.016

3 RESULTS

3.1 EVALUATION OF RESULTS

3.1.1 Summary of results

We evaluated the performance of each MR on its ability to adequately predict abundance indices (AIs) based on three different metrics each using four different model evaluation criteria. The three metrics were:

1. The discrepancy between a predicted, preseason AI and the average AI 3-10 years postseason for the fishery, when AI values from the model have stabilized. The preseason value is a model predicted AI and the 3-10 year average is considered the observed or true AI.
2. The discrepancy between the first postseason AI estimate and the 3-10 year postseason AI values for the fishery. The first postseason value is a model predicted AI and the average of the 3-10 postseason AIs is considered the observed or true AI.
3. The discrepancy between the preseason and the first postseason AI. The preseason value is the model prediction and the first postseason AI is considered the true value.

The last metric has two more years of data than the other two for each AABM fishery. Each of the three metrics was analyzed by comparing four different criteria across the range of MRs estimated used to calculate AI values. The model evaluation criteria are:

1. The mean squared error (MSE) is an average of the squared differences between predicted and observed (true) AIs. It is a measure of the variability of predicted AIs values. The MSE is always positive and hence does not indicate if a MR estimate tends to under- or overestimate the AI. The best MR estimate is the one that minimizes the MSE.
2. The median error is the median value of the difference between predicted and observed AIs. It is less sensitive to outlier values of differences than a mean and provides information on whether a MR tends to under- or over-estimate AIs. The best MR estimate is the one that produces median values closest to zero.
3. The mean absolute scaled error (MASE; Hyndman and Koehler 2006) is a generally applicable, scale-free measure of forecast accuracy. Ideally, the value of MASE will be significantly less than 1. The MASE is always positive and unlike other metrics that are based on averages, it weighs differences between predicted and observed values evenly, regardless of magnitude. The best MR estimate is the one that minimizes the MASE.
4. The mean percent error (MPE) is the average of the difference between predicted and observed (true) AIs divided by the true AI and multiplied by 100%. Because small AI values can correspond to small MSE values, the MPE is a good metric to accompany an MSE as it scales the average differences between predicted and observed AIs accordingly. The best MR estimate is the one that produces MPE values closest to zero.

More information on each of the evaluation criteria and the equations used in the calculations are provided in Appendix D. Results of the analysis are based on MRs that either minimize an evaluation

criterion or provide values close to one. Hence, we present and evaluate the results graphically, by metric (Figures 3.1-3.3).

3.1.2 Preseason AI to Average 3-10 years postseason AI

Of all the MRs examined in the analysis, model evaluation criteria were most often minimized using the 9YA across all fisheries based on discrepancies between preseason and average 3-10 years postseason AIs (Table 3.1, Figure 3.1). MR estimates that minimize model evaluation criteria most often were the 7YA – 11YA estimates. The notable exception is in the SEAK fishery where the MPE and Median error were minimized using the 3YA MR. However, the difference between the median error resulting from the 3YA and the 9YA was small. The predominance of positive values for the median error and MPE indicate that preseason AIs are overestimated relative to the average 3-10 year postseason AI.

3.1.3 First postseason AI to average 3-10 years postseason AI

Discrepancies between the first postseason AI and the average 3-10 year postseason AI are most often minimized using the 3YA MR estimate (Table 3.2, Figure 3.2). However, the differences are small among the model evaluation criteria for the MRs used in the analysis, indicating that this metric may not be sensitive to the 3YA to 11YA MRs. In SEAK, the 10YA minimized both the MSE and MPE and the MASE in NBC. The largest differences are observed using the ETS and LTA MR estimates.

3.1.4 Preseason AI to first postseason AI

In the SEAK fishery, preseason to postseason AIs discrepancies were most often minimized when the Chinook Model used the 9YA MR estimates (Table 3.3, Figure 3.3). However, preseason AI values are slightly overestimated when compared to the first postseason AI.

In the WCVI fishery, the 9YA MR estimate minimizes 2 of the 4 model evaluation criteria. The 8YA MR minimizes the WCVI Median error; however the value is close to that obtained when using the 9YA. The MSE for the WCVI fishery is lowest when using the ETS MR, but the difference from the MSE using the 9YA is small.

Results from the NBC fishery are not as clear. MRs based on the 3YA minimizes the MSE, but the 11YA and ETS MRs minimize the median error and MPE, respectively. Differences from the 9YA for both of these metrics are small.

Table 3.1. Values of the model evaluation metrics for the preseason AI to the average 3-10 year postseason AI discrepancy. Lowest values indicate the MR estimates that create the best predictions from the Chinook model.

MR Estimate	MAE	Median Error	Mean Percent Error	MASE	MAE	Median Error	Mean Percent Error	MASE	MAE	Median Error	Mean Percent Error	MASE
3YA	0.049	**0.005**	**0.080**	0.759	0.034	0.072	0.084	0.760	0.030	0.113	0.254	1.253
5YA	0.039	0.007	0.083	0.679	0.034	0.088	0.081	0.603	0.022	0.117	0.254	1.253
7YA	0.041	0.004	0.085	0.664	0.027	0.071	**0.070**	0.631	0.022	0.118	0.237	1.186
8YA	0.037	0.009	0.090	0.657	0.024	0.080	0.078	0.598	0.021	0.106	0.233	1.198
9YA	**0.033**	0.004	0.092	**0.632**	**0.022**	0.079	0.080	**0.553**	0.019	0.103	**0.191**	1.052
10YA	0.038	0.119	0.108	0.716	0.023	**0.060**	0.090	0.599	0.018	**0.085**	0.196	1.055
11YA	0.043	0.141	0.118	0.762	0.027	0.083	0.100	0.647	**0.018**	0.101	0.190	**1.052**
5YS	0.057	0.181	0.149	0.907	0.035	0.112	0.133	0.809	0.019	0.113	0.189	1.060
1TA	0.071	0.214	0.172	1.004	0.047	0.145	0.160	0.916	0.032	0.149	0.215	1.434

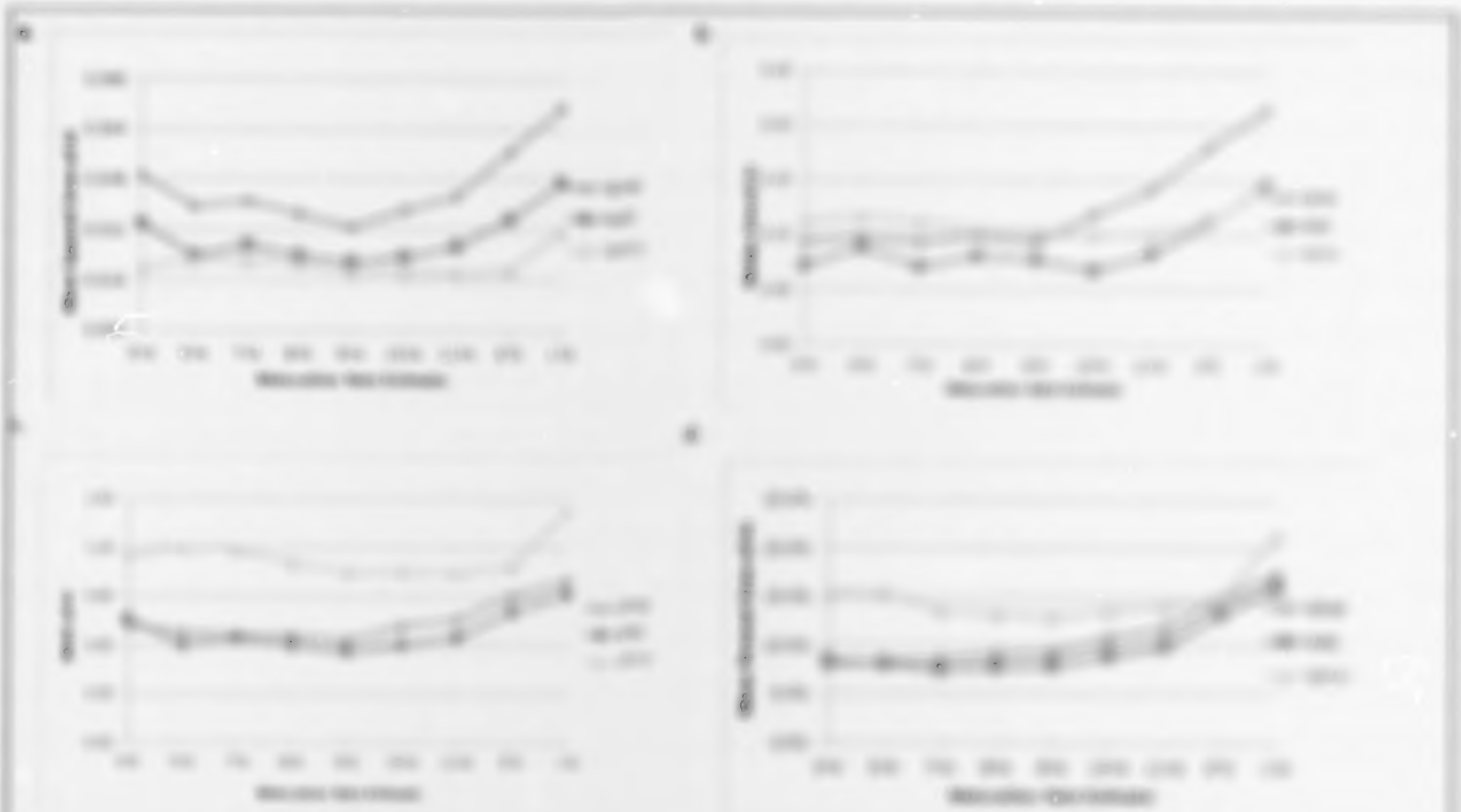

Figure 5.2. Model evaluation metrics of the discrepancy between the predictions of cost life-savings in different cost estimates. a. Mean squared error, b. Median error, c. Mean absolute scaled error, and d. Mean percent error.

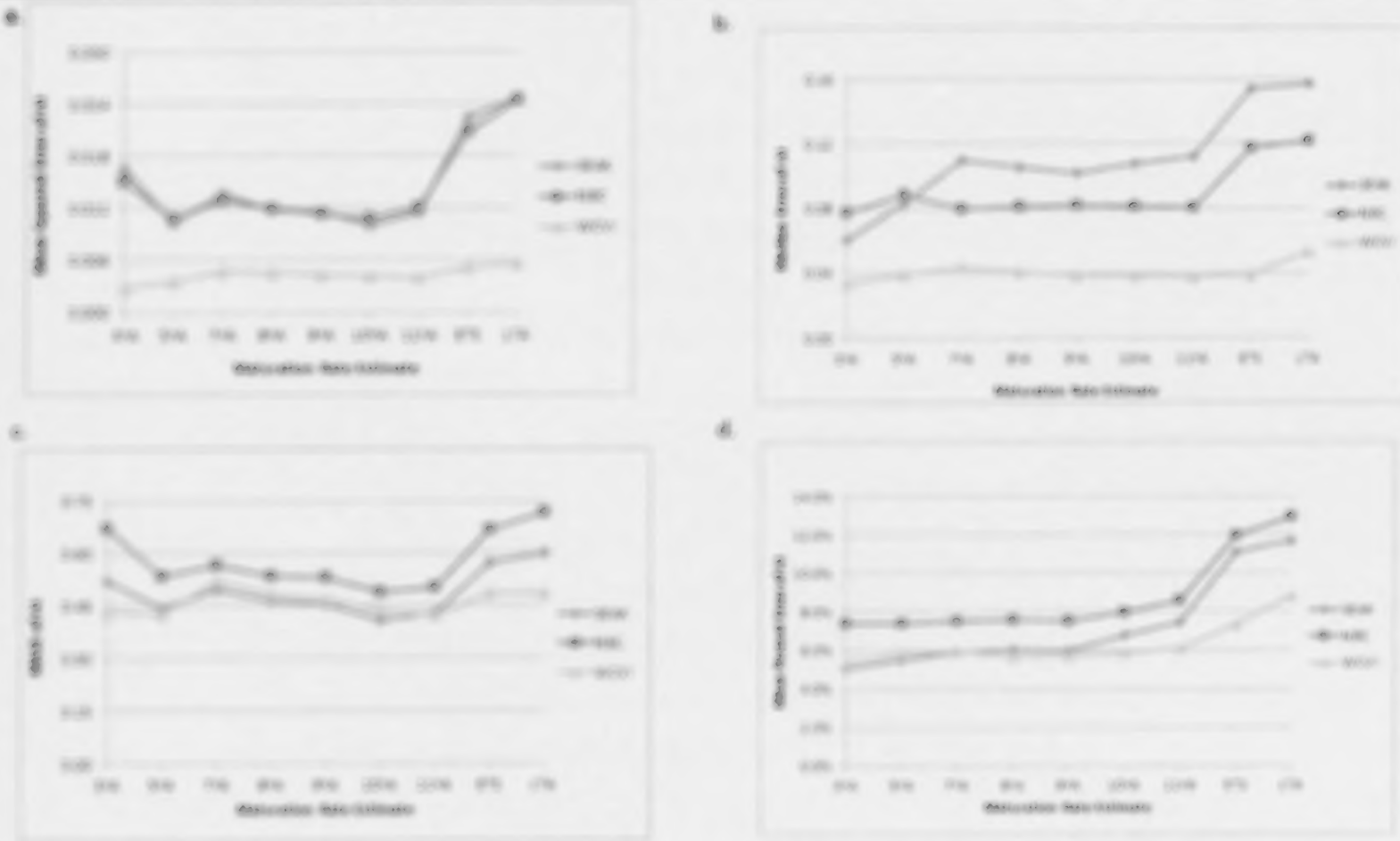

Figure 5.2. Model evaluation metrics of the discrepancy between the first postseason fit and the average 5-10 year postseason fit for different m0 estimates. a. Mean squared error. b. Median error. c. Mean absolute scaled error, and d. Mean percent error.

Table 3.3. Values of the model evaluation metrics for the preseason AI to the first postseason AI discrepancy. Lowest values indicate the MR estimates that create the best predictions from the Chinook Model.

	SEAK				NBC				WCVI			
MR Estimate	MSE	Median Error	Mean Percent Error	MASE	MSE	Median Error	Mean Percent Error	MASE	MSE	Median Error	Mean Percent Error	MASE
3YA	0.029	-0.022	-0.002	0.508	**0.023**	-0.023	-0.016	0.546	0.016	0.043	0.050	0.727
5YA	0.031	0.030	**-0.001**	0.489	0.024	-0.008	-0.017	**0.443**	0.016	0.059	0.050	0.694
7YA	0.030	0.023	0.004	0.487	0.025	-0.039	-0.017	0.510	0.013	0.050	0.045	0.642
8YA	0.030	0.030	0.006	0.510	0.025	-0.019	-0.016	0.479	0.013	**0.035**	**0.043**	0.594
9YA	**0.027**	**0.011**	0.008	**0.435**	**0.023**	-0.015	-0.014	0.451	0.013	0.040	**0.043**	**0.582**
10YA	0.032	0.026	0.013	0.479	0.025	-0.013	-0.012	0.459	0.013	0.044	0.045	0.585
11YA	0.036	0.033	0.015	0.501	0.028	**-0.007**	-0.009	0.467	0.013	0.046	0.047	0.593
ETS	0.033	0.026	0.027	0.506	0.024	-0.011	**0.004**	0.459	**0.012**	0.058	0.049	0.598
LTA	0.037	0.054	0.033	0.536	0.028	0.013	0.008	0.483	0.018	0.072	0.086	0.747

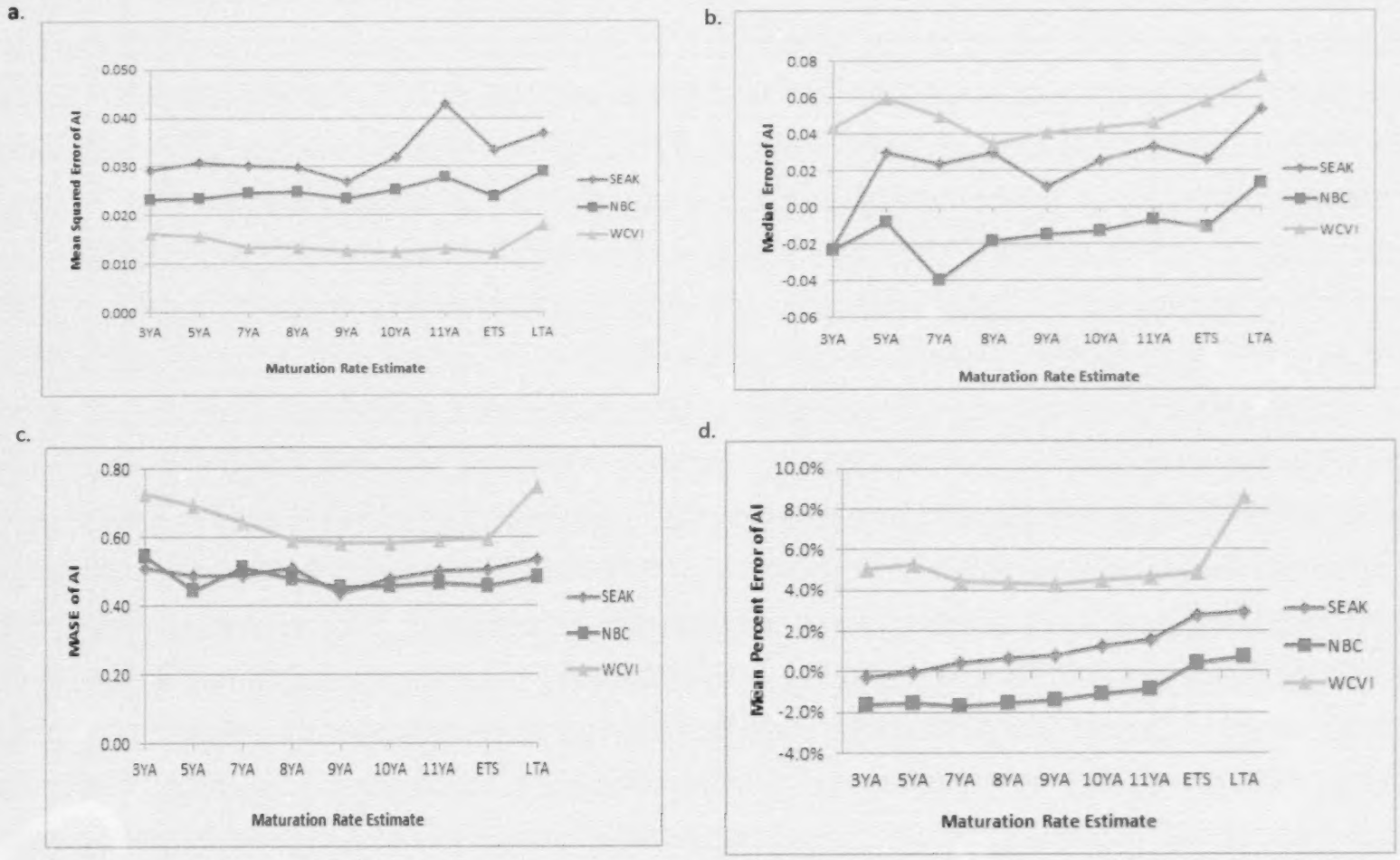

Figure 3.3. Model evaluation metrics of the discrepancy between the preseason and first postseason AI for different MR estimates, a. Mean squared error, b. Median error, c. Mean absolute scaled error, and d. Mean percent error.

3.2 Best Model Choice under Different Data Availability Scenarios

In addition to the evaluation of models for preseason- first postseason discrepancies based on MSE calculations encompassing the 2004-2013 calibration time series, uncertainty in the best projection model was evaluated in response to the extent of time series (i.e., number of calibrations) used for MSE calculations. In some years, more than one model was identified as best because they had identical MSE values but in general the 9YA remained the overall best model (Table 3.4). The first row in this table corresponds to the individual-fishery best model in Table 5.1.

Table 3.4. Best MR projection model for each AABM fishery in response to the number of calibrations included in MSE calculations. The earliest calibration year is 2004 in all cases. The composite is based on the sum of MSE values across fisheries. All models assume a 1Y EV.

Last Year	# Calibrations	SEAK	NBC	WCVI	Composite
2013	10	9YA	3YA	ETS	9YA
2012	9	9YA	5YA	9YA	9YA
2011	8	9YA	5YA, 9YA	9YA	9YA
2010	7	9YA	9YA	9YA	9YA
2009	6	9YA	9YA	9YA, 10YA	9YA
2008	5	9YA	9YA	9YA	9YA

3.3 AI Projections of Alternative Models

Preseason and first postseason AIs from the original annual calibrations were compared to the AIs generated from calibrations using MR and EV combinations with the lowest MSE for the AABMs as a group (9YA MR, 1Y EV) and for the individual AABM fisheries (Table 3.5). The AIs from the original annual calibrations were developed using a LTA MR and 5YA EV prior to 2013 and changed to a 5YA MR and 1Y EV in 2013 following the CTC 2012 MR and EV analysis. The AIs from the original calibrations are generally higher in both preseason and postseason calibrations than those produced using MR and EV from more recent year data for all three AABMs (Figure 3.4). The exception to this pattern occurred for all three AABM fisheries with the 2013 calibration; this corresponded with a change MR and EV assumptions. The biggest difference between the original calibrations and calibrations performed with the 9YA MRs and 1Y EVs occurred in the preseason AIs (Figure 3.4). The effect on the postseason AI was relatively small. The postseason AIs produced by the original and 9YA MRs and 1Y EVs were almost identical for the WCVI AABM fishery.

The average of the preseason and postseason AIs generated from the 2004-2014 Model calibrations using the best fishery-specific MR and EV for the NBC AABM (3YA MRs and 1 Y EV) were similar to the average of the AIs generated by 9YA MR and 1Y EV. For the WCVI AABM, the best fishery-specific MR and EV combination (ETS MRs and 1Y EV) generated across-calibration averages of the preseason and postseason AIs that were identical to the averages using the 9YA MRs and 1Y EVs. The AIs generated using the best MR and EV combination overall AABMs are the same (SEAK) or very similar to the AIs generated using the best fishery-specific MR and EVs.

Table 3.5. Preseason and first postseason AIs from the annual Chinook Model calibration under three MR-EV models.

		Original Calibration a/		Best MR-EV Overall AABM (PFA MR; 17 EV)		Best MR-EV SEAK (PFA MR; 17 EV)	
AABM	Year	Preseason	First Post	Preseason	First Post	Preseason	First Post
SEAK	2004	1.88	2.06	1.81	1.90	1.81	1.90
	2005	2.05	1.90	1.87	1.81	1.87	1.81
	2006	1.69	1.73	1.58	1.62	1.58	1.62
	2007	1.60	1.34	1.51	1.27	1.53	1.27
	2008	1.07	1.01	0.99	0.96	0.99	0.96
	2009	1.33	1.20	1.23	1.16	1.23	1.16
	2010	1.35	1.31	1.22	1.23	1.22	1.23
	2011	1.69	1.62	1.53	1.54	1.53	1.54
	2012	1.52	1.24	1.35	1.26	1.35	1.26
	2013	1.20	1.63	1.30	1.72	1.30	1.72
	Average	1.54	1.50	1.44	1.45	1.44	1.45
		Original Calibration a/		Best MR-EV Overall AABM (PFA MR; 17 EV)		Best MR-EV NBC (PFA MR; 17 EV)	
		Preseason	First Post	Preseason	First Post	Preseason	First Post
NBC	2004	1.67	1.83	1.63	1.70	1.57	1.63
	2005	1.69	1.65	1.54	1.55	1.46	1.59
	2006	1.53	1.50	1.39	1.41	1.45	1.45
	2007	1.35	1.30	1.25	1.04	1.30	1.07
	2008	0.96	0.93	0.85	0.89	0.93	0.90
	2009	1.10	1.07	1.03	1.03	1.04	1.03
	2010	1.17	1.23	1.09	1.17	1.06	1.15
	2011	1.38	1.41	1.29	1.35	1.25	1.30
	2012	1.12	1.15	1.25	1.25	1.18	1.13
	2013	1.10	1.11	1.18	1.19	1.15	1.11
	Average	1.33	1.34	1.25	1.29	1.24	1.28
		Original Calibration a/		Best MR-EV Overall AABM (PFA MR; 17 EV)		Best MR-EV WCVI (CTC Method)	
		Preseason	First Post	Preseason	First Post	Preseason	First Post
WCVI	2004	0.90	0.98	0.87	0.94	0.90	0.96
	2005	0.88	0.84	0.81	0.81	0.82	0.84
	2006	0.75	0.68	0.68	0.66	0.75	0.67
	2007	0.67	0.57	0.63	0.55	0.64	0.55
	2008	0.76	0.64	0.72	0.63	0.67	0.63
	2009	0.72	0.61	0.68	0.61	0.69	0.61
	2010	0.96	0.95	0.93	0.92	0.93	0.94
	2011	1.15	0.90	1.07	0.90	1.09	0.90
	2012	0.89	0.76	0.84	0.74	0.84	0.72
	2013	0.77	1.04	0.84	1.10	0.83	1.05
	Average	0.85	0.80	0.81	0.79	0.81	0.79

a/ Annual calibrations to determine preseason and first postseason AI in 2004-12 were made with a LYA MR and 5YR EV. In 2013, a 5YA MR and a 1Y EV was used in the annual calibration for preseason and first postseason AI.

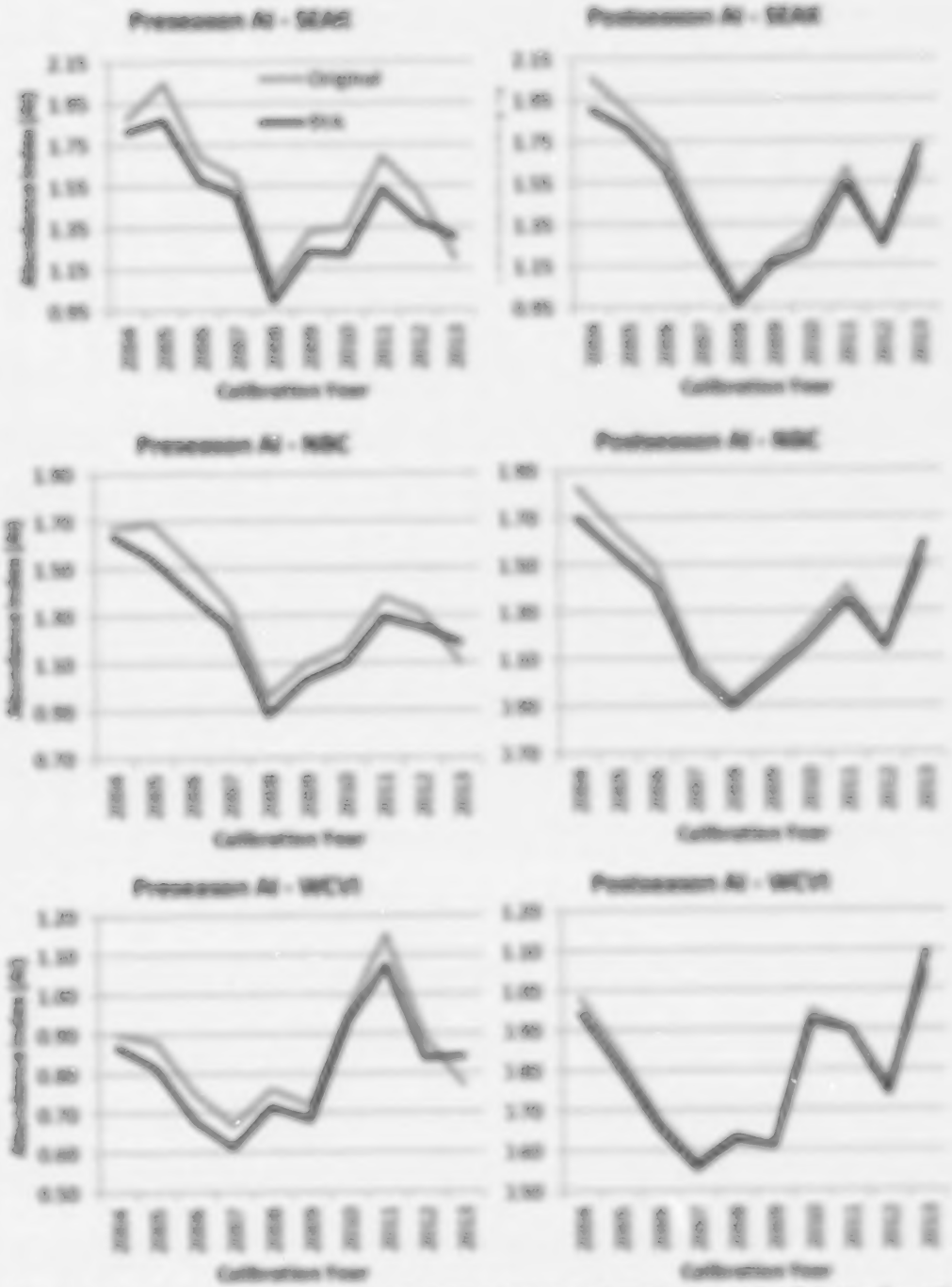

Figure 3.4. Preseason and postseason Ais for the SEAK, NBC and WCVI AABM fisheries from the original 2004-2013 Model calibrations and from calibrations using the this MR and 1Y EV. Comparisons between preseason Ais are displayed in panels on the left, comparisons of postseason Ais in panels on the right. The original values are indicated by a red line in each panel. Values obtained using the this and 1Y EV are indicated with a blue line in each panel.

3.4 Effect of Maturation Rate Estimates on Patterns of Discrepancies between Preseason and Postseason Abundance

Two aspects of the discrepancies between the preseason and first postseason AI for each of the three AABM fisheries have been noted. The first is the magnitude of the discrepancies, with the discrepancy exceeding 20% for two calibrations in each of the three fisheries (see Table 3.6 under the heading Original). The second is that for the annual calibrations from 2005 until 2012, the discrepancies were primarily in one direction for all three AABM fisheries with the preseason AI exceeding the postseason AI (Table 3.6). This pattern was observed despite the occurrence of both decreasing and increasing periods of aggregate Chinook abundance. The most notable exception to the pattern of over-forecasting of the AIs occurred with the calibration in 2013 (see Table 3.6).

Comparison of the magnitude of the percent error between the preseason and first postseason AIs from the original Chinook Model calibrations and from calibrations based on the best fishery-specific estimation model as assessed using the MSE statistic (Table 3.6, compare values under Original and MSE) showed that the mean percentage error (MPE) was reduced for the SEAK and WCVI AABM fisheries but not for the NBC fishery. For the NBC fishery, the MPE was reduced most using ITS-WBs and IY-EVs. The MPE from the original calibrations for the NBC fishery was small and results from calibrations performed with WR-EV estimates from the two other estimation models included in Table 3.6 produced similar results. The estimation model that resulted in lowest fishery-specific MPE differed from the model that resulted in the lowest fishery-specific MSE for each AABM fishery. The difference between the two models was small in each case. The WR-EV estimation model did affect the magnitude of the calibration-specific percent error between the preseason and postseason AIs as well as the MPE. In terms of absolute percentage errors, the employment of the IYR in SEAK and WCVI reduced the percentage errors by 10% and 16% on average, and the ITS and IYR both reduced the percentage errors by 12% in the NBC fishery (bottom 2 rows in Table 3.6). The percent error could be reduced in most calibration years through adoption of a different estimation model than had been used in calibrations prior to 2013 and the IYR-WR and 1:1-EV emerged as the best overall choice. The WR-EV estimation model, however, did not substantially change the pattern of percent errors observed across consecutive calibrations in years 2004-2013 for the AABM fisheries (Figure 3.5), meaning other factors or model inputs beyond WR or the EV have had a causative effect. An actual change in sign of the error occurred in only some cases where the percent error was near zero in the original calibration (Table 3.6). There was a slightly greater effect for the WCVI AABM fishery but overall, the influence was relatively minor (Figure 3.5). For the purpose of illustrating that the overall pattern of errors was not vastly affected by the WR-EV estimation model, results from a limited selection of estimation models was selected for display in Figure 3.5. Results were similar, however, for any of the estimation models that were investigated.

Table 5.6. Percent error (PE) between the preseason and first postseason W- from Chinook Model calibrations 2004–2013 for the SUS, NBC and WCVI AABM fisheries. For each fishery, pre-season W- values from: 1) the original Chinook Model calibrations (for years 2004–2012, the CYD was used and in 2013 the CWQ CEV was used), 2) from calibrations based on the fishery-specific estimation model resulting in the lowest MAE, and 3) from calibrations based on the fishery-specific estimation model with the lowest MPE. The bottom three rows contain the overall mean of the percent errors (MPE), the mean of the absolute percentage errors (MAPE) and the percentage reductions in errors compared to the original columns.

	SUS AABM			NBC AABM			WCVI AABM		
Cle Year	Original	(W4) years (ranch)	(W4) years (ranch)	Original	(W4) years (ranch)	(CR) years (ranch)	Original	(CR) years (ranch)	(W4) years (ranch)
2004	46.7	46.7	46.4	46.7	46.7	46.4	46.2	46.2	46.2
2005	7.9	8.2	8.9	2.4	46.2	1.4	9.8	10.6	10.6
2006	4.4	4.7	4.1	2.8	8.8	5.1	18.3	21.4	13.6
2007	28.8	28.8	28.5	23.7	23.9	25.3	17.5	25.2	28.9
2008	5.8	5.2	6.2	5.3	5.3	6.5	28.8	7.6	18.3
2009	25.8	8.8	8.8	2.8	3.8	3.8	28.5	21.7	21.3
2010	5.3	6.8	8.8	4.8	7.8	9.8	5.3	4.5	1.6
2011	8.2	8.5	5.4	2.3	6.8	5.7	27.8	28.1	28.1
2012	23.5	8.2	7.8	18.7	8.8	18.4	17.8	28.5	15.8
2013	28.2	28.8	28.8	27.1	28.8	29.1	28.8	21.8	23.8
MPE	8.7	8.8	8.1	8.5	8.2	8.5	8.1	8.5	8.1
MAPE	15.3	7.8	8.8	8.3	8.4	9.1	18.5	14.5	13.1
% Reduction		15.4%	38.4%		11.4%	10.9%		21.4%	30.0%

* Note that a 1-yr average for SUS and NC stocks and 4-yr average for SCV stocks was used in the 2013 CLE

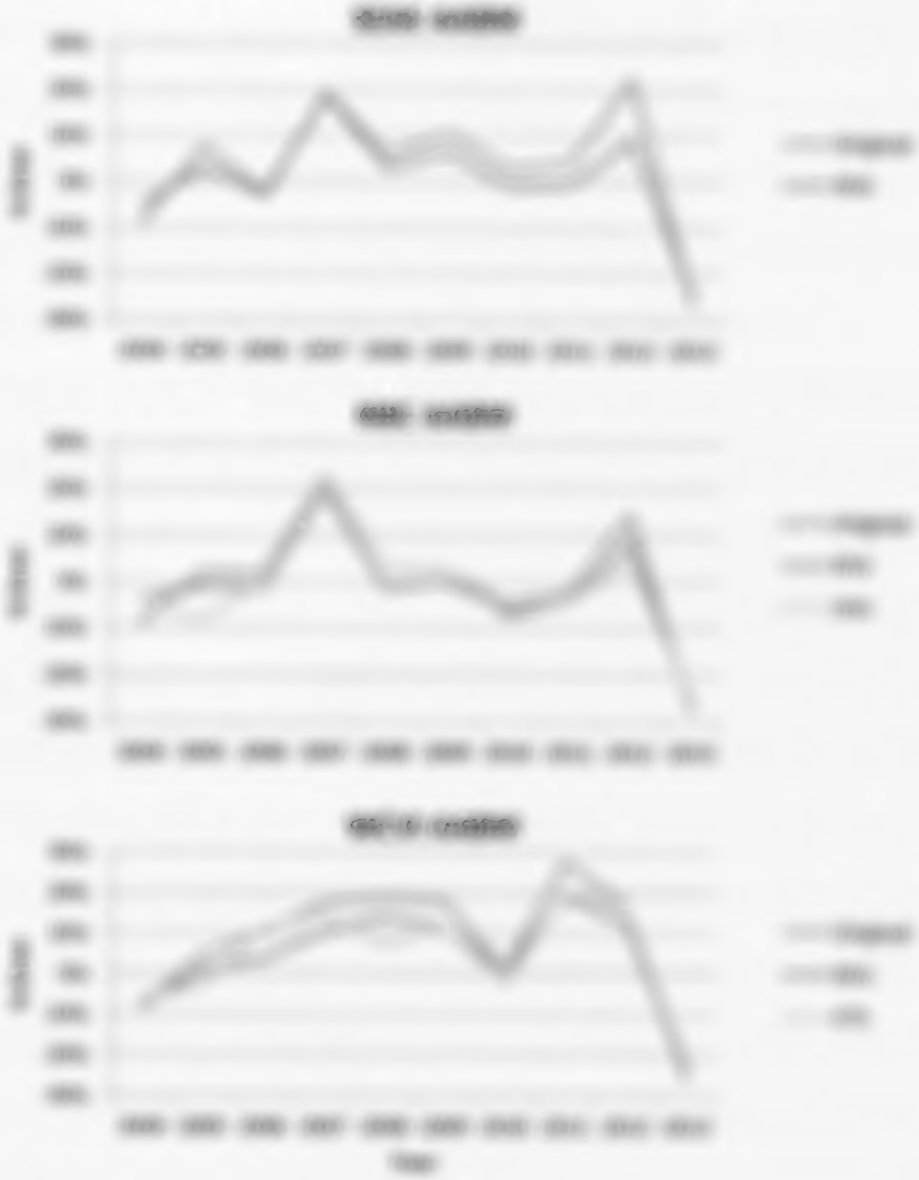

Figure 4.2 - Revised curve between the prescription and the consequence. In (a), (b), (c) and (d) it is stated [illegible] three original data (1999-2001) [illegible] calibrations. Once the calibrations are performed using the (a) and (c) model [illegible] overall it providing (c) comparable [illegible] and [illegible] [illegible] [illegible]

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Table 6.1 Interest Rates Quotations in MMKT, FXT and Currency Swaps for up to 1 year complementary interest changes in each MMKT, FXT, aggregate MMKT, aggregate FXT, aggregate MMKT, aggregate FXT, aggregate MMKT, aggregate

Table 3.11. Salmon River Hatchery (SRH) CWT stock Cohort outputs by age 2-6, and complimentary North Oregon Coast (NOC) stock aggregate (SA) outputs derived using Cohhak methods and estimated NOC Terminal Return (TR, spawning escapement plus terminal fishing mortality), 1999 brood year. (CO = cohort number of fish, PTF=pre-terminal fishing mortality, PTFR = PTF/CO, TRprop = proportion of total returning fish, MR = maturation rates)

	SRH CWT Stock						NOC SA					
Age	CO	PTF	PTFR	TR	TRprop	MR	CO	PTF	PTFR	TR	TRprop	MR
2	12,533	185	0.01	202	0.04	0.02	1,367,838	20,187	0.01	25,698	0.06	0.02
3	8,552	681	0.08	1,481	0.3	0.19	925,866	74,057	0.08	89,852	0.19	0.10
4	5,072	826	0.16	2,062	0.42	0.49	609,536	99,032	0.16	192,213	0.42	0.38
5	1,966	606	0.31	1,059	0.22	0.83	286,370	99,949	0.35	108,913	0.24	0.58
6	197	80	0.41	125	0.02	0.99	65,757	28,366	0.43	41,391	0.09	1.00

Table 3.12. SRH CWT stock/NOC SA ratios, by age, for Proportion of total Terminal Return and MRs, 1985, 1988, 1989, 1992, and 1999 brood years, with means.

	Proportion of Total Terminal Return						MR					
Age	1985	1988	1989	1992	1999	Mean	1985	1988	1989	1992	1999	Mean
2	1.24	3.52	1.48	3.24	0.73	2.03	1.34	4.59	1.57	3.68	0.86	2.41
3	0.99	1.01	2.12	3.03	1.55	1.74	1.07	1.37	2.34	3.59	1.81	2.04
4	1.21	1.14	0.90	0.45	1.00	1.04	1.21	2.12	1.17	0.69	1.29	1.32
5	0.89	0.50	0.69	1.30	0.90	0.85	1.03	0.96	0.85	1.34	1.42	1.12
6	0.80	0.67	2.29	0.28	0.26	0.86	1.00	0.97	1.00	0.99	0.99	0.99

4 Discussion

4.1 Relevance of the SYA Model

This investigation showed that amongst the models used to project MRs, including the ETS models, the SYA performed best across KMZRF fisheries and for different subsets of calibrations in terms of minimizing composite MSEs and maximizing percentage error reductions. The 2012 analysis identified the SYA projections of MRs (and most recent EV) as the best, but the SYA (and most recent EV) model was not examined in 2012. However, the biological or technical basis behind the good performance of the SYA model at minimizing the discrepancies between preseason and first postseason AEQ are unknown. At the core of this analysis is the examination of MR estimation models for incomplete broods. Two types of MR models were considered in the analysis. The average model (Section 2.2) is applied uniformly across all stock and ages, whereas the ETS model (Section 2.3) fits an exponential smoothing model to each stock and age. Both models are able to capture recent trends, but the ETS model also attempts to capture any long term trends that may be present. The ETS model is more complex in terms of the number of parameters to process. No examination of the biological or technical basis for the performance of either of the models was performed.

The analysis conducted herein did not seek to find the biological mechanism behind any of the models because such an exercise would be time intensive, outside the scope of the assignment, and due to the complexity would likely be inconclusive. There are some possible reasons why the best model, the 9YA MR and 1Y EV, outperformed all the rest. One potential biological explanation to the best MR model is that it incorporates the MR from the last two complete broods. And similarly, a technical explanation is that the 9YA MR model, across all stocks and ages, provides the optimal level of smoothing to minimize the preseason and postseason discrepancy.

4.2 AIs and Maturation Rates

MRs affect the number of fish estimated to remain available to ocean fisheries during the Chinook Model calibration process. This investigation examined the MR projection assumptions and its impact on the preseason and postseason AIs. From these comparisons, the quantification of preseason error relative to the first postseason AI is germane for PST monitoring of AABM fisheries performance. Ordinarily, the same assumptions have been employed for incomplete broods of all stocks and ages and for the one-year projection necessary for Chinook Model calibrations. These assumptions have been discussed given the detection of trends in MRs for some stocks and the different degree of variability in the time series of MRs display across stocks and ages (Appendix B). The development of models and methods to improve the ability to predict stock- and age-specific MRs is important to avoid confounding of inter-relationships between data involving multiple stock and fisheries across years. The exploration of stock- and age-specific methods (the average and ETS models) included in this report responds to this realization. However, additional investigation is important because robust projection of MRs transcends their influence on discrepancies between preseason and postseason AIs - i.e., the development of robust projections of MRs helping to cope with incomplete broods and future expectations of MR values would have a positive influence on the estimation of other relevant statistics derived from the exploitation rate analysis in addition to its relevance for AIs.

PSC Chinook Model AI forecasting involves a large number of data inputs, algorithms and assumptions, and only a systematic exploration of the interaction between these factors would help to understand and improve the forecasting abilities of the PSC Chinook Model and therefore enable the possibility of reducing even more AI discrepancies. More specifically, perfect information about MRs will not produce perfect AI forecasting or eliminate preseason-postseason discrepancies because many other factors affect the Chinook Model forecasting procedure. This observation points to the need for further investigation into other aspects of the Chinook Model that may influence its performance, including forecasts, estimates of terminal runs, delays in obtaining CWT and some escapement data, as well as base-period data and assumptions.

4.3 Data Quality

One limitation of projecting MRs is gaps in the brood-year time series of MRs of some stocks. These gaps are the consequence of no CWT releases for a given stock and year or invalid broods characterized by extremely poor marine survival and sparse CWT recoveries producing anomalous statistics in cohort analyses. The ETS methodology, as applied in this exercise, is the only one using calendar-year data directly from the MATAEQ files (see Appendix C for more detail), and therefore uses time series of MRs

without gaps. However, the problem of gaps in time series of MRs affects all models used for projections. This situation arises because infilling or inputting assumptions are necessary (averages are currently used) in order to complete the time series of brood-year MRs and create the gap-free time series of calendar-year MRs necessary for the MATAEQ file. For the average models, the impact of invalid broods means less data is used to compute the recent average. Future investigations on the use time series models (including the ETS model) to estimate MRs can include their application at the brood-year level with or without infilling or inputting missing values in the time series. Without infilling, for instance, the time series algorithms used herein would be based on the longer string of subsequent brood-year MR values if the time series has gaps. Different infilling procedures could be explored in the future, including a revaluation of whether or not the data quality of MR time series warrants changes in the list of stocks currently in the MATAEQ file. Additionally, there are potential improvements to be realized with the incorporation of additional stocks into the MATAEQ file to better represent those stock groups present in contemporary fisheries.

4.4 Retrospective Comparisons with Complete-Brood Maturation Rates

The ability to produce robust projections of MRs for incomplete broods and for one-year forecasts is important for other analyses the CTC conducts annually, including statistics derived from exploitation rate analysis and the fitting procedures involved in Chinook Model calibrations. Finding models that take into consideration the unique characteristics of time series of observed MRs exhibited by each stock and age is therefore important. A straightforward way of evaluating the performance of models used to project MRs is to compare the projected values with those obtained by cohort analysis of completed broods. An example of such comparisons is shown in Appendix A and appendices E to H for a subset of models. This kind of retrospective evaluation has the potential of providing insights about the effect assumptions intrinsic in estimation models have on the magnitude of discrepancies with observed (actual) MR values. A thorough evaluation of these discrepancies could increase the reliability of selected models and improve the quality of all statistics affected by incomplete broods.

4.5 Differences between Maturation Rates for CWT Indicator Stocks and for Stock Aggregates

A complication to the MR analysis above is that the MR estimates used in the PSC Chinook Model assume that a stock aggregate (SA) and its CWT indicator stock share the same maturation and exploitation rates. This demonstration analysis shows that if the age structure of a CWT indicator stock is substantially different from that of the natural populations it is meant to represent then it is unavoidable that MRs of the CWT indicator stock will improperly represent those of its stock aggregate. If such is common for the stock aggregates in the Chinook Model, almost all of which have hatchery CWT indicator stocks, then the Chinook Model's ability to accurately estimate pre-terminal fishery AIs, both preseason and postseason, would be compromised because the Model will fit to the inputted CWT indicator stock MRs.

Estimation of AIs would likely be improved by using stock aggregate MR inputs based on summed estimates of terminal return for the component populations of the stock aggregates. There are some stock aggregates for which data to do this for the various component populations is extremely limited or absent. For such stock aggregates, however, it may still be preferable to use the method shown here to estimate MRs for those natural populations for which data is available and to use those MR estimates as more likely representative of the MRs of the entire natural stock aggregate than the MRs for the CWT indicator stock.

The time-frame for potential implementation of the methodology demonstrated here is uncertain because the method has only very recently been developed and must be considered by the full CTC under PSC Commission guidance. It is unknown how adjustment to using naturally-produced stock aggregate MRs will influence the Chinook Model's forecasting abilities, but this seems likely to result in improvement in AI estimates. In any case, going through the exercise of calculating SA MRs will better inform the Chinook Model and its underlying assumptions as well as increase our understanding of the processes driving changes to AIs.

5 SUMMARY

Recent discrepancies between the preseason and postseason AI prompted the PSC Commissioners to task the CTC-AWG to update the previous MR-EV analysis. The previous MR and EV investigation conducted by the CTC in 2012 on a limited number of MR-EV models found that the MR-EV model that minimized the MSE was a 5YA MR and a 1Y EV (TCChinook 14-1 V1). In updating the analysis, the AWG confirmed that use of various other models resulted in smaller discrepancies between the preseason and postseason AIs generated by the Chinook Model, across calibrations, compared to the LTA and 5YA MRs. According to the composite MSE metric, the MR-EV model that minimized the preseason to postseason AI discrepancy across the three AABM fisheries was the 9YA MR and 1Y EV (Table 5.1; see Appendix I for details). Though a different estimation model produced the smallest discrepancy between the preseason and first post-season AI for each AABM fishery across Model calibrations 2004-2014 based on the fishery-specific MSE.

The CTC recommends that the 9YA MR and 1Y EV is used for the annual Chinook Model calibration. Given this departure from the MR average used in previous Chinook Model calibrations, it may be advisable to periodically reassess whether the 9YA MRs continue to provide the best overall approach to minimizing the discrepancy between the preseason and postseason AIs generated by the Chinook Model across calibrations.

The investigation of the ETS method did demonstrate that it was possible and feasible to employ a time series modelling approach. While the 9YA emerged as the overall recommended approach to estimate age-specific MRs for stocks in the Chinook Model's MATAEQ input file, the ETS method also showed promise. This method, in fact, generated the best overall results in terms of precision (MSE) for WCVI (Table 5.1) and in terms of accuracy (MPE) for NBC (Table 3.3). Future investigation of time series approaches for the projection of MRS can include applications of the ETS model to brood year-based MRs and the exploration of ARIMA models. One challenge that was encountered was the need to infill gaps in the MR time series which can occur due to missing or invalid broods; these are brood years that

were tagged, but had such low survivals that CWT recoveries were either absent or produced nonsensical MRs, and the LTA was used. The infilling can be achieved but the best approach to do so could not be determined in the time frame of this investigation.

Stock aggregate MRs are different than CWT indicator stock MRs. Results using data from the North Oregon Coast show that there is a large discrepancy between naturally-produced stock aggregate MRs and hatchery CWT indicator stock MRs, which could result in errors in both preseason and postseason AIs because the model will fit to the inputted CWT indicator stock MRs. The results also indicate that CWT MRs may be biased high for any age given the earlier maturation of the hatchery stock versus the natural stock. Given that nearly all driver stocks use a hatchery indicator (e.g., Fraser Lates), this approach to adjust the maturation rates for the natural stocks has potential to improve abundance predictions.

As noted above, other factors and inputs undoubtedly contribute to errors in forecasting AIs. These include, but are not limited to, preseason forecasts, delays in obtaining CWT data and some terminal run and catch data, escapement estimation, etc. A future examination of forecasting relative abundance should examine issues like these with the same rigor applied in this investigation.

Table 5.1. Mean squared error between the preseason and first postseason AI assuming a 1-year EV. The scenario that minimized the MSE is highlighted in darker shading and the second best scenario is lighter shading.

Model	SEAK	NBC	WCVI	Composite
3YA	0.0289	0.0233	0.0161	0.0683
5YA	0.0309	0.0238	0.0157	0.0704
7YA	0.0300	0.0246	0.0132	0.0678
8YA	0.0299	0.0248	0.0134	0.0681
9YA	0.0268	0.0234	0.0125	0.0627
10YA	0.0320	0.0252	0.0125	0.0696
11YA	0.0357	0.0277	0.0131	0.0765
LTA	0.0374	0.0283	0.0180	0.0836
ETS	0.0333	0.0239	0.0122	0.0695

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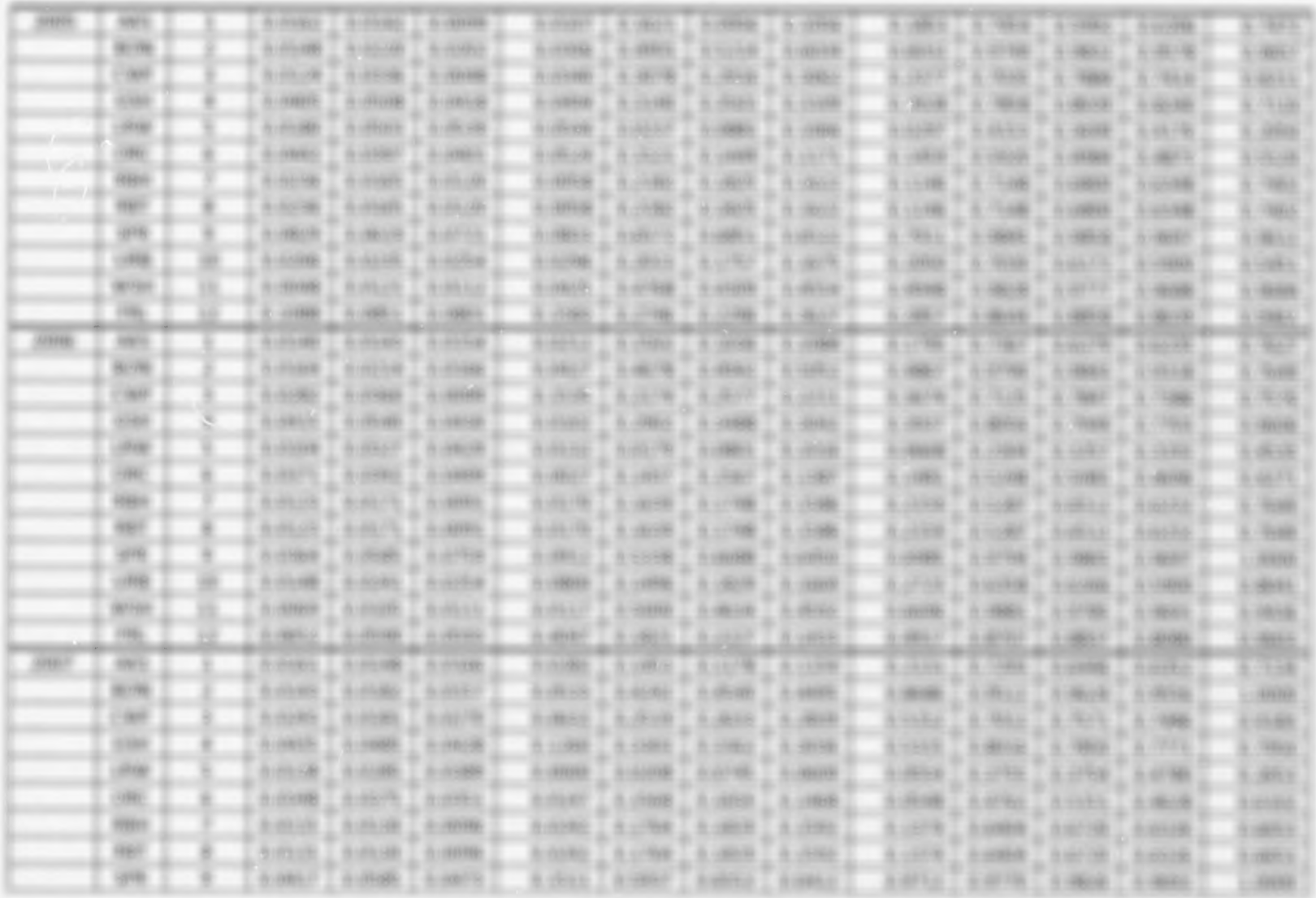
APPENDICES

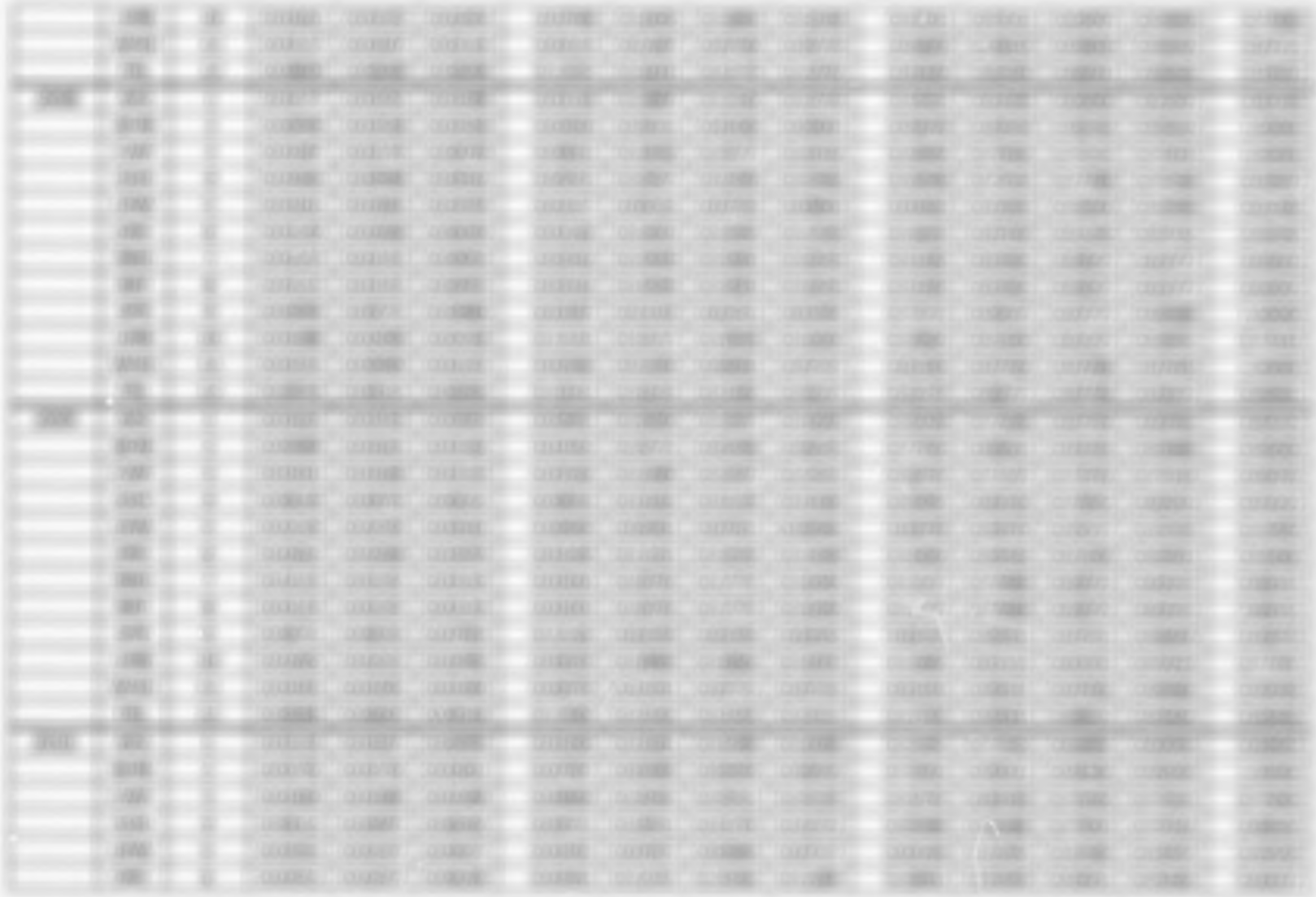
Appendix A. Estimated and Observed MRs at Three Ages from Completed Broods for Each of the 12 Model Stocks in the MATAEQ Input File for the 2004-2014 Chinook Model Calibrations.

The estimated values were constructed using three models: 1) an average of the three most recently completed and valid broods (3YA); 2) an average of the nine most recently completed and valid broods (9YA), and 3) a projection using a time series exponential smoothing model (ETS). Estimates from the 3YA, 9YA and ETS models were included because each produced the lowest fishery-specific MSE for one of the AABM fisheries. For the average models, invalid broods were not replaced with other values in the computation of averages (see Section 2.2). The first, second and third age is 3, 4 and 5 respectively for the two spring stocks (AKS and WSH). The first, second and third age is 2, 3 and 4 respectively for the other (fall) stocks. All observed values are from the cohort analysis procedure completed by the CTC-AWG in March 2015 for CWT indicator stocks associated to the Chinook Model stocks in the MATAEQ file. The most recent year with CWT recovery data in this analysis was 2014 for Chinook Model stocks AKS, GSH, RBH and RBT and 2F/13 for all others. An observed MR is given for only those stock-brood-age combinations where the brood was complete in the 2015 cohort analysis results.

Table A.1. The name of the Chinook Model stocks in the MATAEQ file and the associated CWT indicator stock is provided at the end of this appendix.

			First Age				Second Age				Third Age			
CLB YR	Stock	Stock #	3YA	9YA	ETS	Observed	3YA	9YA	ETS	Observed	3YA	9YA	ETS	Observed
2004	AKS	1	0.0187	0.0151	0.0193	0.0078	0.1448	0.0892	0.1049	0.3152	0.6862	0.5747	0.6129	0.7049
	BON	2	0.0236	0.0392	0.0263	0.0215	0.4988	0.5320	0.5972	0.2230	0.9792	0.9833	0.9561	0.8869
	CWF	3	0.0153	0.0359	0.0075	0.0135	0.2705	0.2635	0.2278	0.1414	0.7773	0.7887	0.7560	0.4718
	GSH	4	0.0374	0.0505	0.0420	0.1171	0.2578	0.3473	0.2838	0.2595	0.7305	0.8065	0.7677	0.8000
	LRW	5	0.0472	0.0895	0.0680	0.0412	0.1092	0.1027	0.1115	0.1230	0.6600	0.3505	0.4187	0.6034
	ORC	6	0.0461	0.0414	0.0678	0.0241	0.1516	0.1407	0.1155	0.1243	0.5058	0.4405	0.4443	0.4064
	RBH	7	0.0189	0.0188	0.0192	0.0127	0.1574	0.1619	0.1573	0.3015	0.7028	0.6662	0.6318	0.7170
	RBT	8	0.0189	0.0188	0.0192	0.0127	0.1574	0.1619	0.1573	0.3015	0.7028	0.6662	0.6318	0.7170
	SPR	9	0.0710	0.0586	0.0746	0.1059	0.6282	0.6716	0.6491	0.5962	0.9771	0.9851	0.9686	0.9680
	URB	10	0.0225	0.0270	0.0294	0.0369	0.1731	0.1661	0.1641	0.2160	0.7197	0.5952	0.5926	0.4709
	WSH	11	0.0036	0.0134	0.0114	0.0241	0.3955	0.4454	0.4464	0.6229	0.9763	0.9725	0.9677	0.9730
	FRL	12	0.0792	0.0767	0.0779	0.1100	0.2554	0.2591	0.2106	0.3191	0.8907	0.9056	0.8417	0.7992





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	[illegible]	7	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
	[illegible]	8	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
	[illegible]	9	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	1.[illegible]	0.[illegible]	0.[illegible]	1.[illegible]
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	[illegible]	11	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
	[illegible]	12	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
[illegible]	[illegible]	1	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
	[illegible]	2	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	1.[illegible]
	[illegible]	3	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]
	[illegible]	4	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
	[illegible]	5	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]
	[illegible]	6	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]
	[illegible]	7	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
	[illegible]	8	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
	[illegible]	9	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	1.[illegible]
	[illegible]	10	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]
	[illegible]	11	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]
	[illegible]	12	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
[illegible]	[illegible]	1	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]
	[illegible]	2	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	—
	[illegible]	3	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	0.[illegible]	—	0.[illegible]	0.[illegible]	—

	GSH	4	0.0889	0.0620	0.0759	--	0.4109	0.3798	0.4322	--	0.9444	0.8632	0.9156	1.0000
	LRW	5	0.0116	0.0199	0.0152	--	0.0471	0.0471	0.0408	--	0.4748	0.3805	0.4356	--
	ORC	6	0.0214	0.0193	0.0127	--	0.1063	0.1191	0.1213	--	0.5255	0.5303	0.5636	--
	RBH	7	0.0217	0.0150	0.0125	--	0.2084	0.1888	0.1681	--	0.7357	0.6885	0.6545	0.7940
	RBT	8	0.0217	0.0150	0.0125	--	0.2084	0.1888	0.1681	--	0.7357	0.6885	0.6545	0.7940
	SPR	9	0.0869	0.0710	0.1131	--	0.8401	0.7078	0.6769	--	0.9959	0.9864	0.9733	--
	URB	10	0.0877	0.0438	0.0671	--	0.2128	0.2018	0.1789	--	0.7126	0.6442	0.6139	--
	WSH	11	0.0215	0.0163	0.0295	--	0.6299	0.5446	0.7575	--	0.9892	0.9795	0.9726	--
	FRL	12	0.1252	0.1360	0.1645	--	0.3478	0.3052	0.3789	--	0.9186	0.9070	0.9232	0.9378
2014	AKS	1	0.0282	0.0220	0.0343	--	0.2620	0.2245	0.2878	--	0.8597	0.7811	0.8345	--
	BON	2	0.0342	0.0253	0.0426	--	0.7087	0.5576	0.7537	--	0.9867	0.9520	0.9628	--
	CWF	3	0.0609	0.0494	0.0387	--	0.2704	0.2760	0.3600	--	0.8490	0.8133	0.8758	--
	GSH	4	0.0618	0.0638	0.0789	--	0.4391	0.3993	0.4563	--	0.9128	0.8775	0.9003	--
	LRW	5	0.0116	0.0198	0.0149	--	0.0471	0.0470	0.0402	--	0.4748	0.3799	0.4173	--
	ORC	6	0.0138	0.0174	0.0198	--	0.1831	0.1450	0.2050	--	0.6064	0.5242	0.5612	--
	RBH	7	0.0214	0.0155	0.0216	--	0.1490	0.1821	0.1546	--	0.6914	0.7078	0.6399	--
	RBT	8	0.0214	0.0155	0.0216	--	0.1490	0.1821	0.1546	--	0.6914	0.7078	0.6399	--
	SPR	9	0.1274	0.0886	0.1199	--	0.8217	0.7190	0.7306	--	0.9958	0.9869	0.9746	--
	URB	10	0.0756	0.0483	0.0776	--	0.2401	0.2099	0.2461	--	0.7251	0.6725	0.6884	--
	WSH	11	0.0147	0.0183	0.0347	--	0.6086	0.5734	0.6650	--	0.9927	0.9787	0.9835	--
	FRL	12	0.1165	0.1430	0.1511	--	0.3542	0.3509	0.4945	--	0.9579	0.9163	0.9274	--

Table A.2 The following table provides the name for each Chinook Model stock in the MATAEQ files and the associated CWT indicator stock:

Sequence in MATAEQ file	Model Stock Acronym	Model Stock Name	CWT Indicator Acronym
1	AKS	Alaska Spring	AKS
2	BON	Lower Bonneville Hatchery	LRH
3	CWF	Cowlitz Fall Hatchery	CWF
4	GSH	Lower Georgia Strait Hatchery	BQR
5	LRW	Lewis River Wild	LRW
6	ORC	Oregon Coastal	SRH
7	RBH	WCVI Hatchery	RBT
8	RBT	WCVI Wild	RBT
9	SPR	Spring Creek Hatchery	SPR
10	URB	Columbia River Upriver Bright	URB
11	WSH	Willamette Spring Hatchery	WSH
12	FRL	Fraser Late	CHI*

* Note: The MRs for the Fraser Late aggregate stock, consisting of the Harrison River natural stock and the Chilliwack River Hatchery stock, are calculated external to the MATAEQ program using a method that relies on the observed MRs for CHI CWT indicator stock.

Appendix B. Graphical Presentation of the Time Series of Brood-Specific MRs at Age, the Stock-Specific Cohort-Based Survival Rate for the Youngest Mature Age and the Mean Age of Maturation for the Suite of Individual and Composite Chinook CWT Indicators.

Data used to generate all figures presented in this appendix originated from or were based on results of the annual CWT-based exploitation rate analysis (ERA) carried out by the CTC-AWG in March 2015.

Two side-by-side panels are presented for each CWT indicator stock. The three-letter acronym used for each CWT indicator appears at the top of each panel. The stock name for each indicator and other information such as geographical location is given in a table which follows after the series of graphs. Each panel displays the following time series by brood:

Left panel: This panel shows the rate of maturation on a scale from 0 to 1 for each age with recovery data. The commonly used acronym for the CWT indicator appears above the panel as well as the oldest age with recovery data used in the cohort analysis procedure for the stock. The range and number of ages of maturing fish varies among stocks but the youngest age included in the cohort analysis procedure is 2 and the oldest is 6. The range of ages is typically 3 – 6 for spring stocks and is either 2 - 5 or 2 - 6 for summer and fall stocks. The same line color indicates the same numerical age for every stock (red = 2, blue = 3, green = 4, purple = 5 and grey = 6). The time series for each stock includes all broods for which the analysis was completed. A gap in the time series at all ages in a brood indicates that no CWTs were released. A gap in the time series for the oldest age only indicates that the no CWTs were observed at the oldest age and thus the brood was complete (MR = 1) at the next-to-oldest age. Age-specific estimates for incomplete broods are shown as colored dots. The estimates for incomplete broods were calculated by assuming a MR equal to the average of the five most recently completed broods for the oldest available age of mature fish. All MR values were extracted from the calendar year ('CYR') version of the brood-specific 'OUT' files which are generated as a standard output by the cohort analysis program.

Right panel: Two time series are displayed in the right panel. One time series is the mean age of maturation (indicated by the line in a lighter blue color) and it is associated with the left-hand Y-axis scale ranging from 2 – 6 years. The second is the cohort-based survival rate for tagged smolts to the first age vulnerable in fisheries (indicated by the line in a darker blue color) and it is associated with the right-hand Y-axis scale. The youngest age is 2 for summer and fall stocks and age 3 for most spring stocks, though 2 in a few cases. This survival rate, expressed as a percentage out of 100, is a statistic automatically produced by the cohort analysis procedure used by the CTC-AWG in the analysis of CWT recoveries and it was extracted from the stock-specific 'SVRC.csv' output file.

The mean age of maturation, equivalent to generation time in semelparous species (Wootton and Smith 2015), is a brood-specific composite value in years which incorporates the rate of maturation across all ages included in the cohort analysis. It can be calculated using the following two approaches:

1) Mean Age of Maturation (with fishing effects) $= \frac{(\prod_{a=min}^{a=max}(a * Esc_{BY,a}))}{TotEsc_{BY}}$

Where a = age, with possible values ranging from 2 - 6 depending on the stock, $Esc_{BY,a}$ = estimated CWT escapement at age for a brood year, and $TotEsc_{BY}$ = total escapement for the brood. Values will lie between the observed minimum and maximum ages with mature fish for a given stock.

This formulation uses the estimated CWT escapement as determined from the CWT sampling programs and population estimation method employed for each CWT indicator stock. It also reflects size- (and therefore, age-) selective effects of pre-terminal and terminal fisheries which influence the population 'escaping' to spawning locations. These effects are likely to have stock, age and calendar year dependencies due to the particular set of fisheries impacting a stock and the magnitude and regulations characterizing each fishery in a given year. A second formulation of the mean age of maturation metric was developed to remove the potential influence of fishing effects on the mean age of maturation. It was used in the figures presented in this appendix.

2) Mean Age of Maturation (fishing effects removed) $= \frac{(\prod_{a=min}^{a=max}(a * EscNF_{BY,a}))}{TotEscNF_{BY}}$

Where a = age with possible values from 2 - 6 depending on the stock. The total brood escapement with fishing effect removed, $TotEscNF_{BY}$, is obtained in an analogous fashion to the total of the conventional estimated CWT escapement for a brood:

$$TotEscNF_{BY} = \left(\sum_{a=min}^{a=max} EscNF_{BY,a}\right)$$

The escapement at age with fishing effects removed, starting with the youngest and proceeding to the oldest in sequence, $EscNF_a$, is obtained with the following set of equations:

1) $EscNF_{a1} = (CohANM_{a1} * MR_{a1})$

2) $EscNF_{a2} = \left((CohANM_{a1} * MR_{a1}) * SR_{a2}\right) * MR_{a2}$

3) $EscNF_{a3} = \left(\left(\left(CohANM_{a1} * MR_{a1}\right) * SR_{a2}\right) - EscNF_{a2}\right) * SR_{a3}) * MR_{a3}$

4) $EscNF_{a4} = ((((((CohANM_{a1} * MR_{a1}) * SR_{a2}) - EscNF_{a2}) * SR_{a3}) - EscNF_{a3}) * SR_4) * MR_{a4}$

5) $EscNF_{a5} = (((((((CohANM_{a1} * MR_{a1}) * SR_{a2}) - EscNF_{a2}) * SR_{a3}) - EscNF_{a3}) * SR_4) - EscNF_4) * SR_5) * MR_{a5}$

Terms in the above equations are brood-specific. Values are obtained from the cohort analysis procedure used by the CTC-AWG to conduct the annual ERA, and they are defined as follows:

$CohANM_{a1}$ = cohort size, after over-wintering natural mortality has occurred, for the youngest age of maturing fish for a stock (and brood)

MR_{a1} to MR_{a5} = MR at age, from the youngest to oldest age, for a stock (and brood)

SR_{a2} to SR_{a5} = survival rate at age, from the second youngest to oldest age

The age subscript (a) of 1 - 5 refers to the five (though typically four) possible ages of maturation starting with the youngest (a1) to the oldest (a4 or a5, depending on the stock). For fall and summer stocks the span of actual ages is 2 – 5 (a1 – a4), though there are a few cases of 2 – 6 (a1 – a5). For these stocks the second actual age is 3. For spring stocks, the span of actual ages is 3 - 6 and for this adult life history pattern, the second actual age is 4.

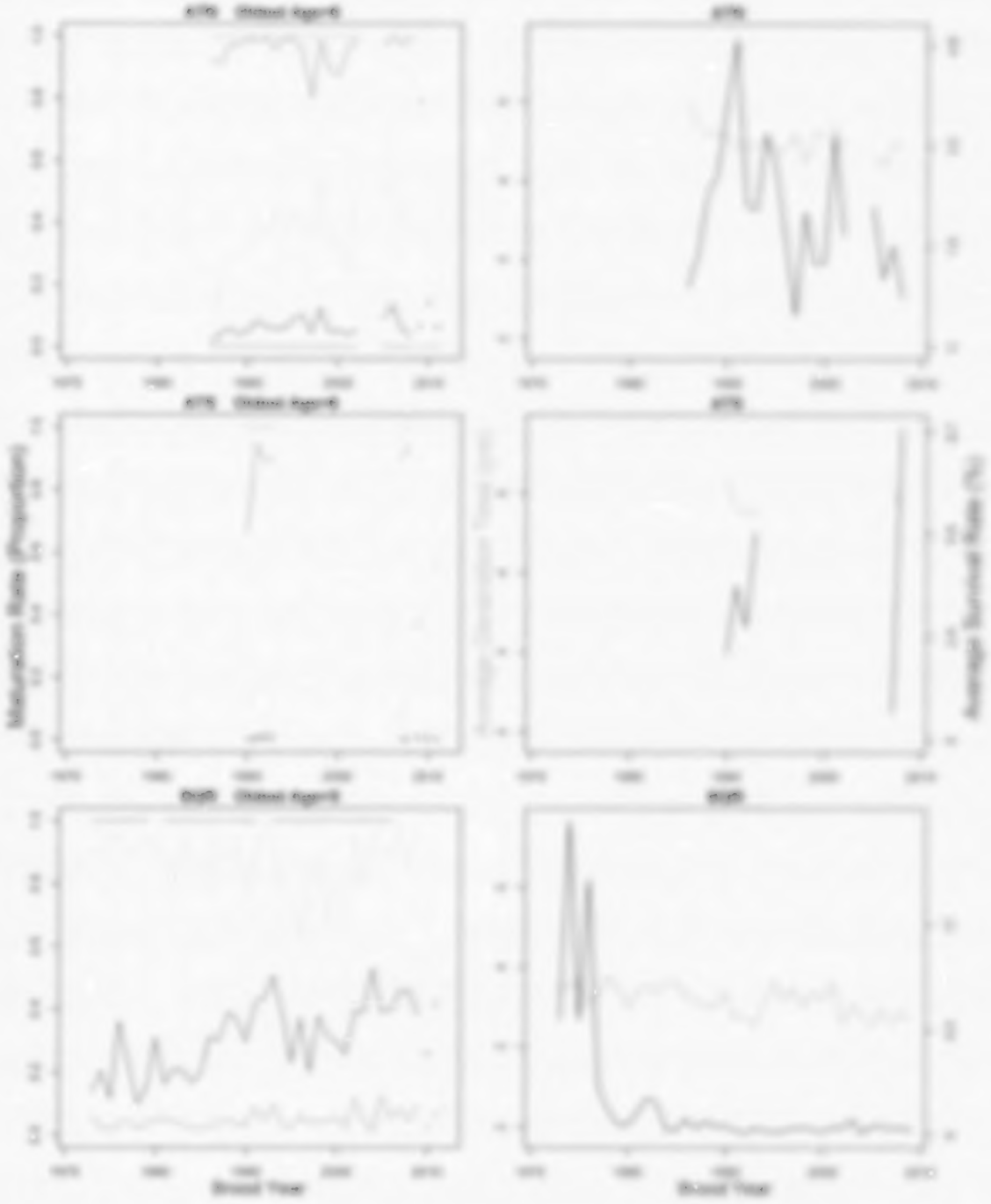
The survival rates (Sa) are age-specific constants employed by the CTC in the cohort analysis procedure and expressed as proportions. They are 0.7, 0.8 and 0.9 for the second through fourth ages of maturation. For stocks with an additional fifth age, 0.9 is also used.

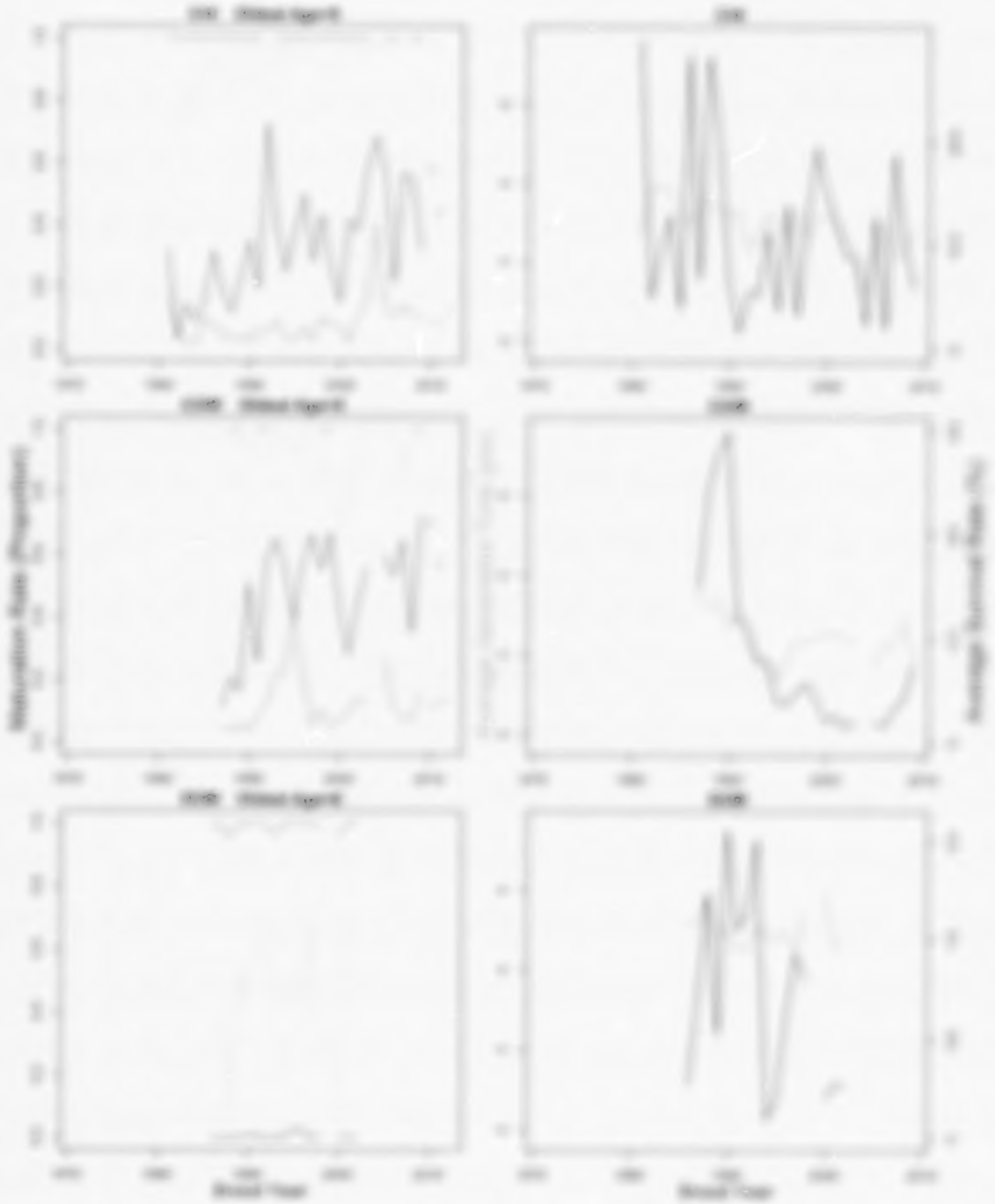
The mean age of MR metric is an integration of the age-specific MRs which can change in opposite direction from one brood to the next. The overall effect of these changes at age within a brood can be difficult to determine and the mean age of maturation metric captures the overall effect in a single value. It's useful for revealing trends in the maturation pattern across successive broods. A pattern of an increase in the MRs at age across broods (i.e., an increasing proportion of fish are maturing at younger ages) will tend to correspond with a declining trend in the mean age of maturation, and vice versa.

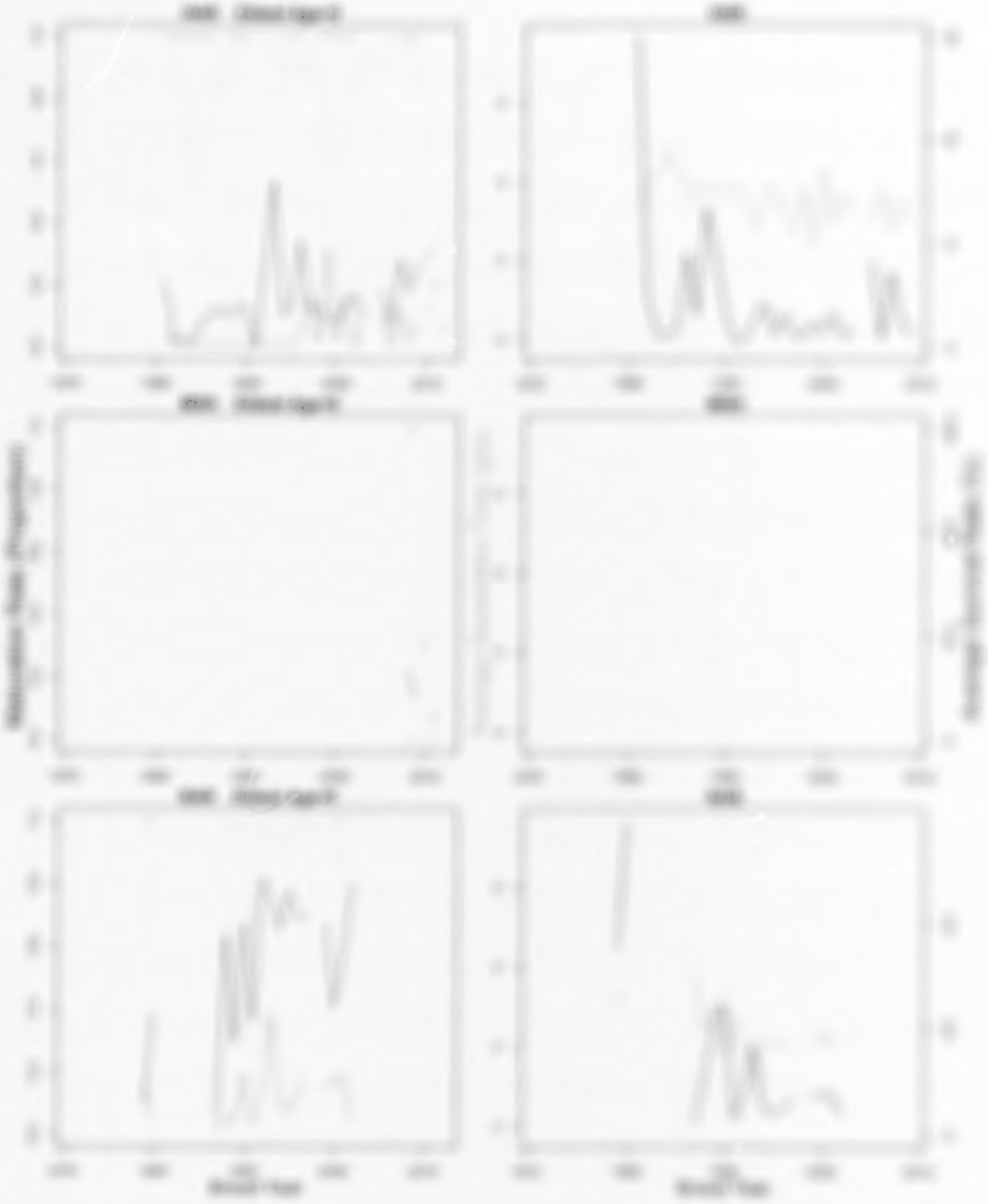
Trends exist in the age-specific MRs for a number of the CWT indicator stocks (e.g., QUI, GAD, LYY and SPS), including some of the CWT indicators which contribute MR data for Model stocks in the calibration of the Chinook Model (e.g., AKS, BQR, SPR and WSH). The most common pattern is a trend toward increasing rate of maturation and an overall effect of earlier maturation schedule is supported by a corresponding declining trend in the mean age of maturation. As an indication of a directional tendency, the slope of a line of simple linear regression was obtained from the complete data set for each CWT indicator associated to a Chinook Model stock with the following results:

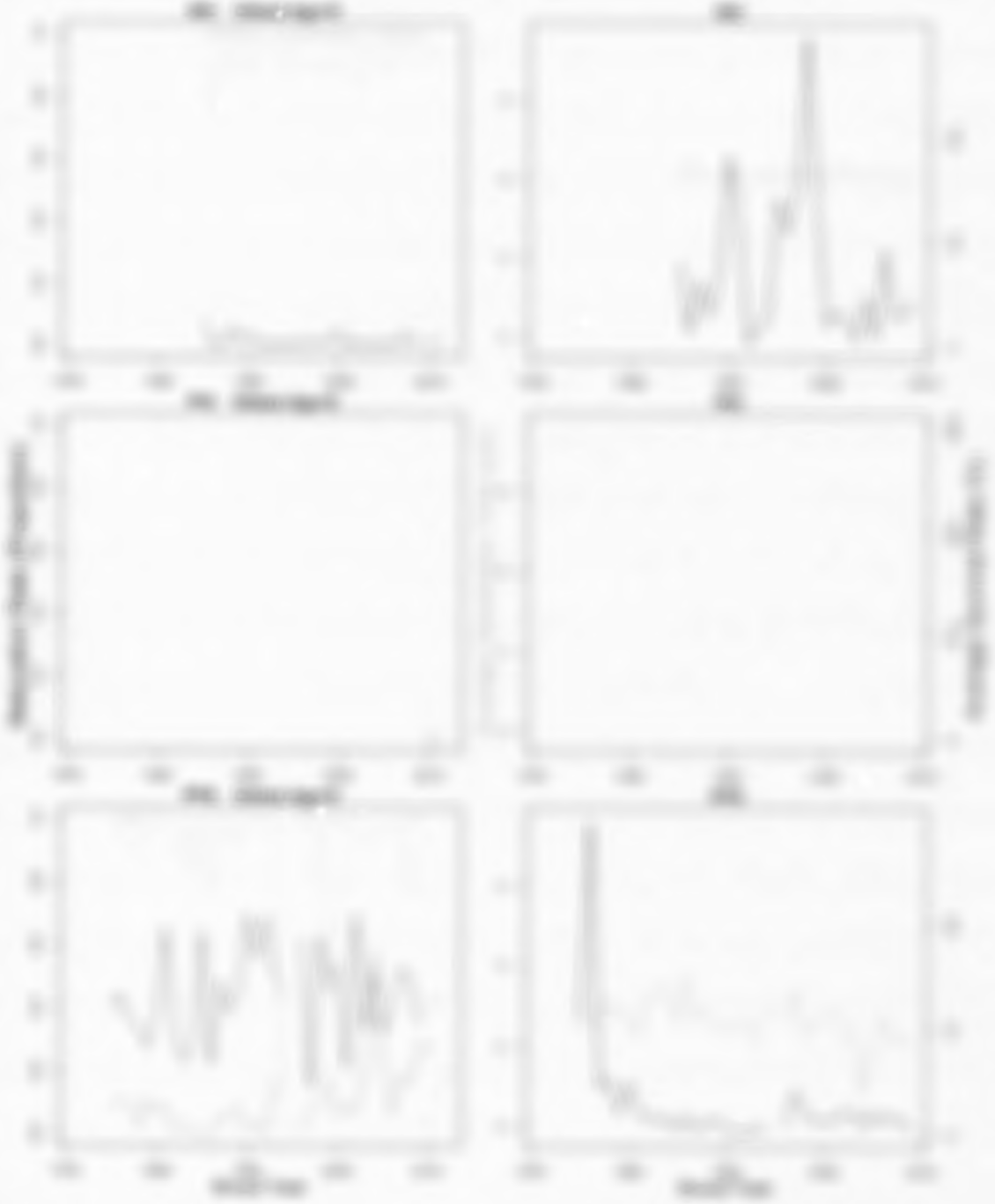
CWT Indicator	Model Stock	Slope from Linear Regression
BQR	GSH	-0.0099
RBT	RBT, RBH	+0.0006
CHI	FRL	-0.0230
HAR	FRL	-0.0170
AKS	AKS	-0.0080
CWF	CWF	-0.0140
LRW	LRW	+0.0200
LRH	BON	-0.0094
SRH	ORC	-0.0076
SPR	SPR	-0.0089
URS	URB	-0.0047
WSH	WSH	-0.0060

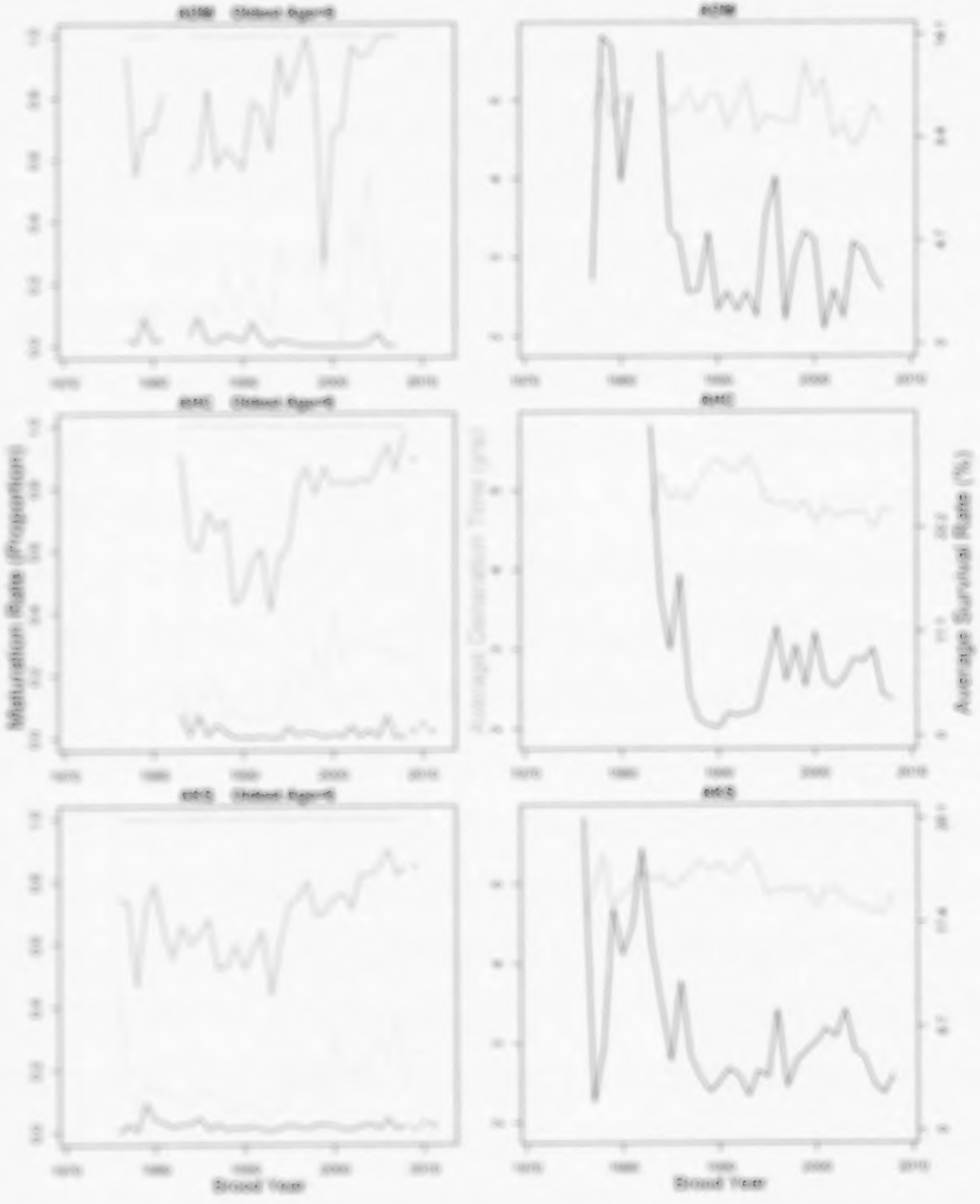
This review across stocks indicates that a pattern of increasing rates at one or more ages and a declining trend in the mean age of maturation has occurred in all regions. The direction of trend in mean age of maturation was downward for all but two of the stocks (RBT and LRW). It has also occurred in stocks considered predominantly natural (e.g., transboundary stocks STI and TAK and the northern BC stock KLM) as well as those considered dominated by releases of hatchery-origin Chinook salmon (e.g., BQR and LRH).

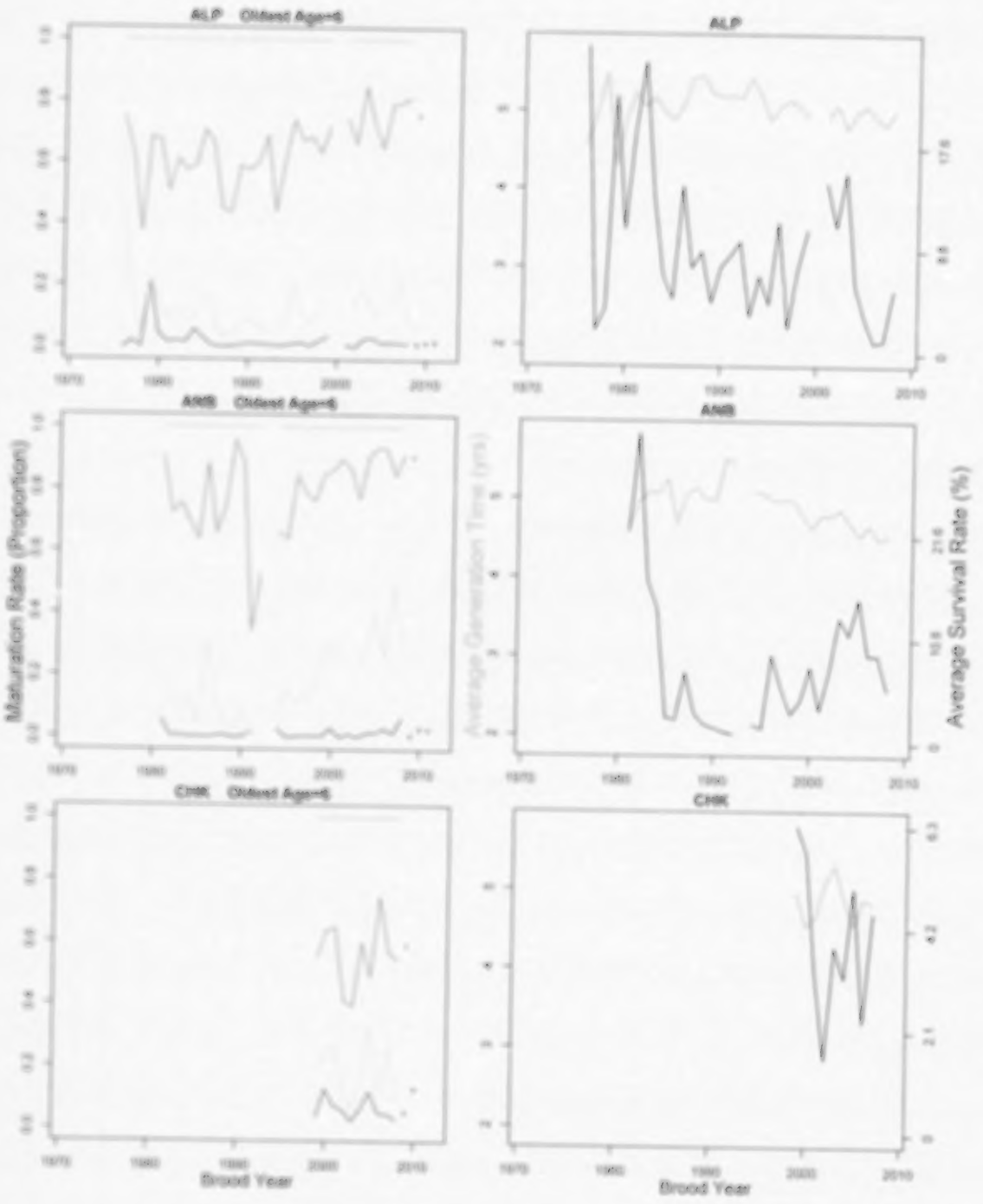

Mortality Rate (Proportion)
Average Survival Rate (%)
Brood Year
Brood Year

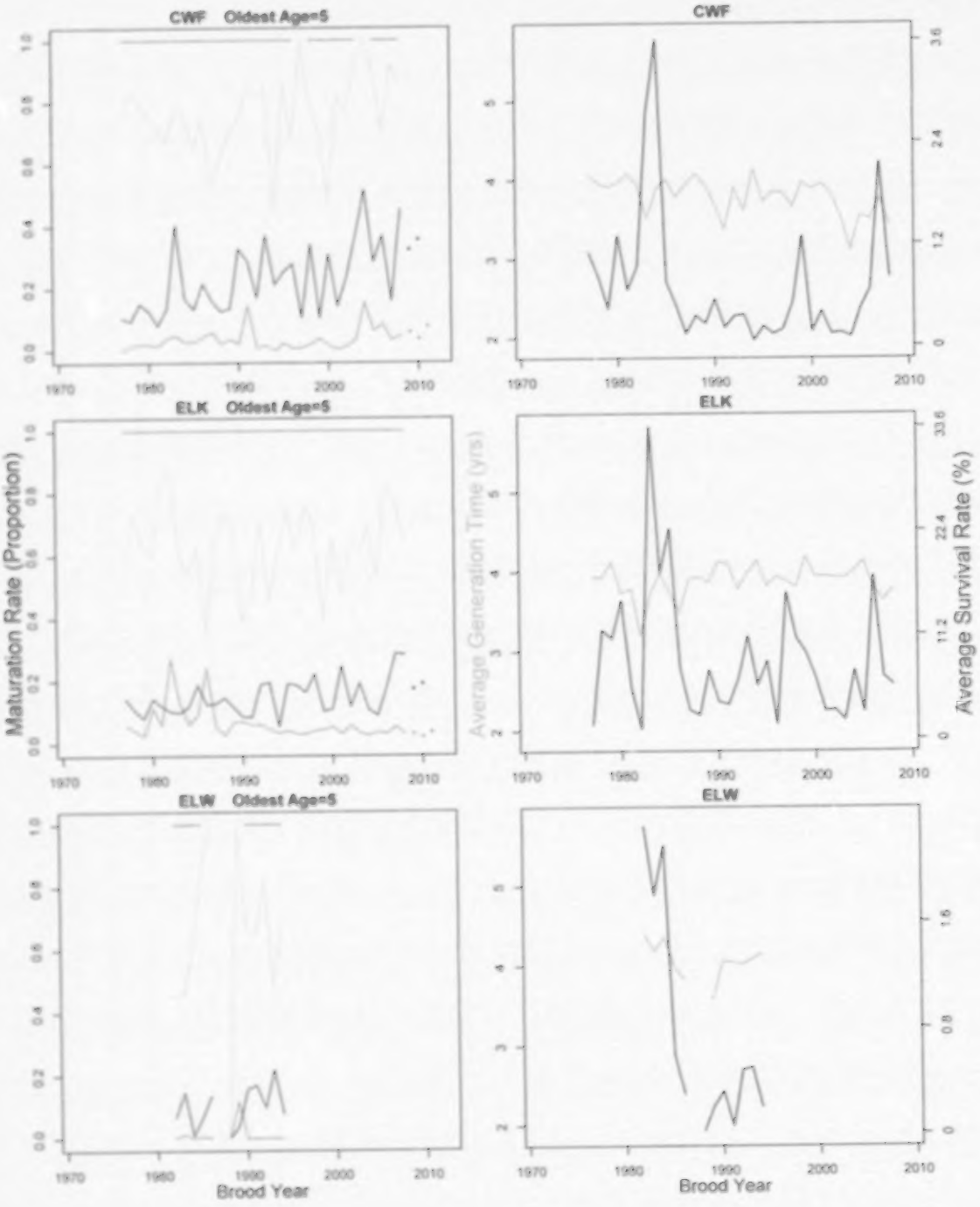

Harvest Rate (Proportion)
Average Survival Rate (%)
Brood Year
Brood Year

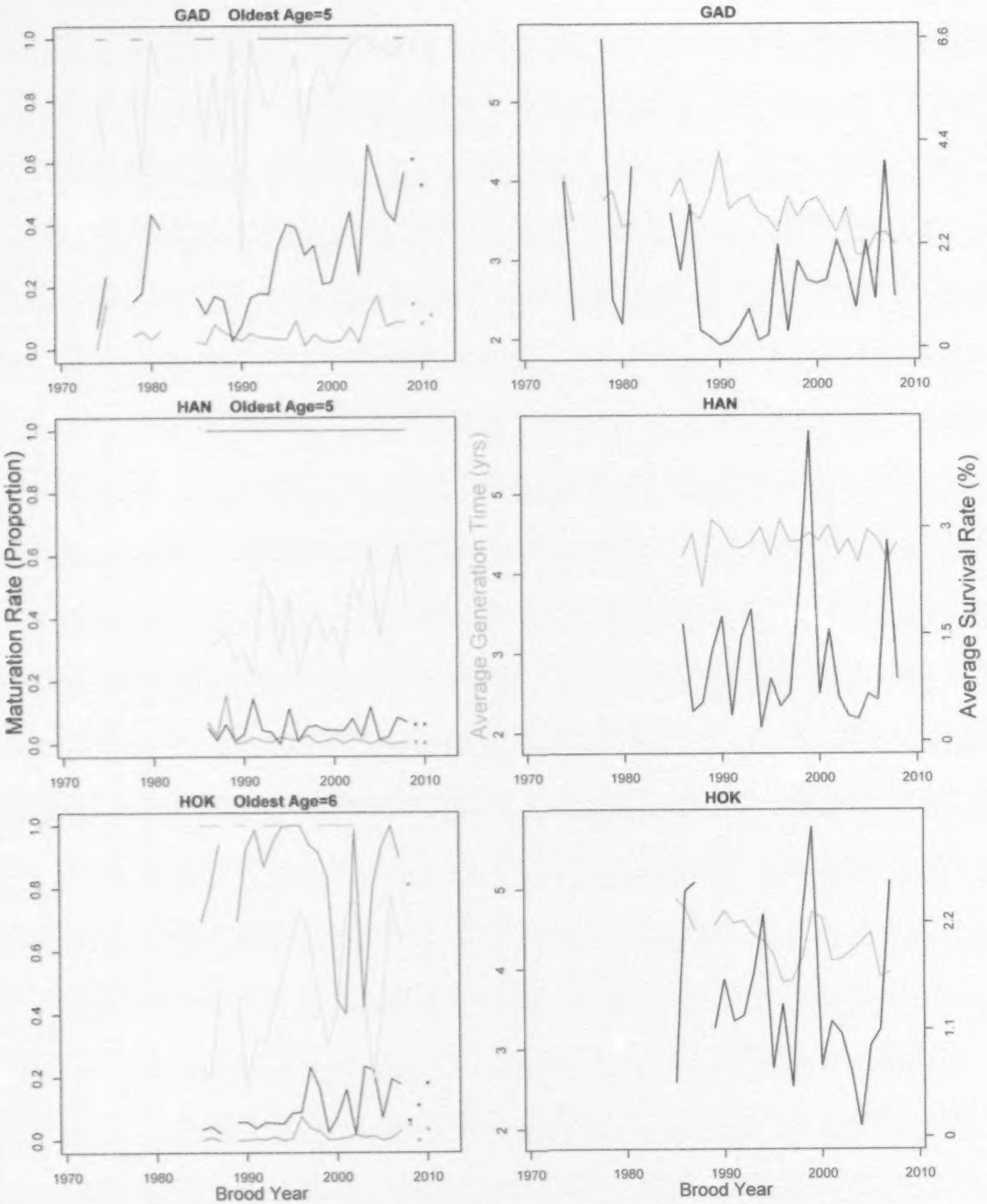

Absolute Rate Proportion
Average Accounts Daily Use
Account Year
Account Year

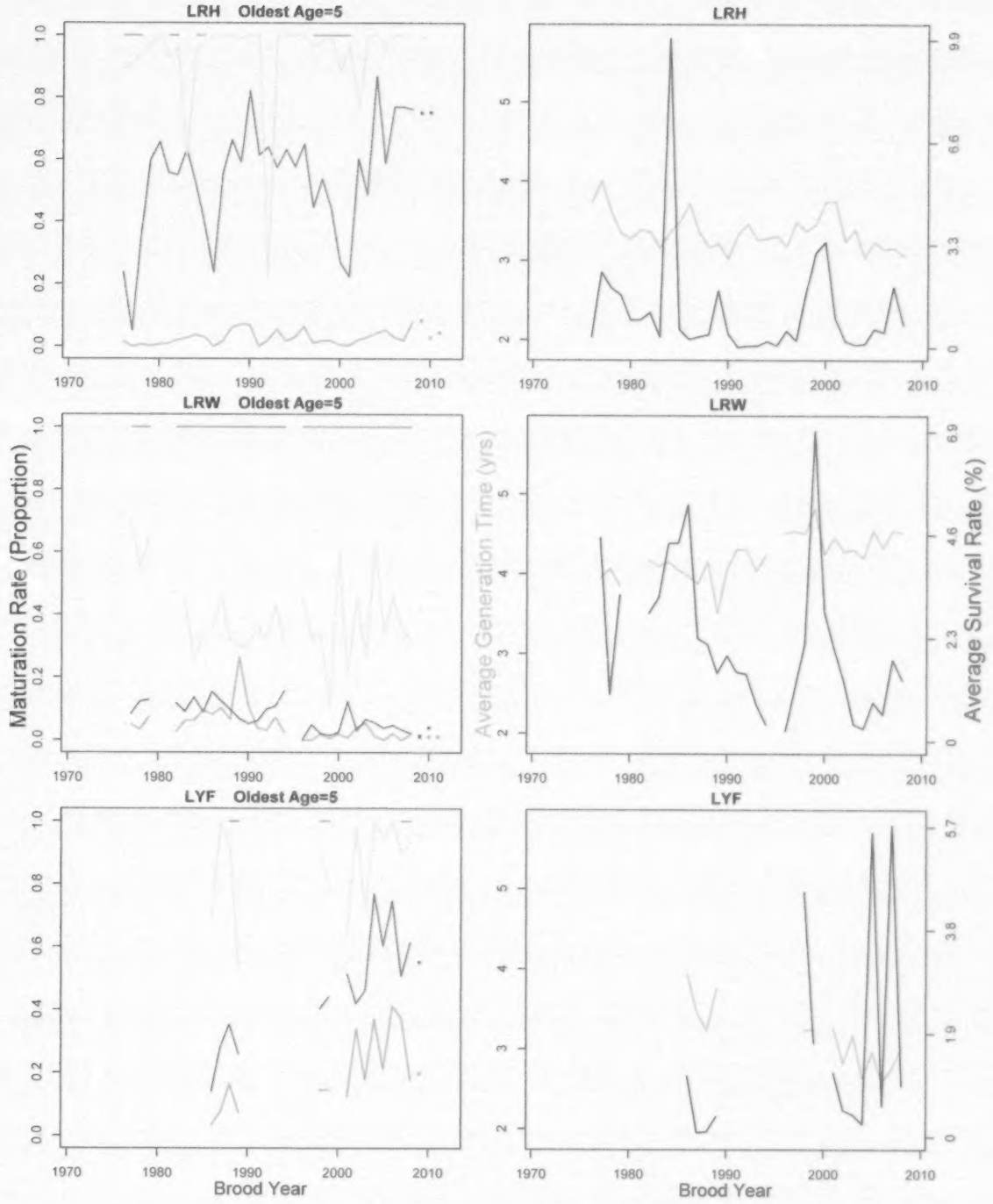


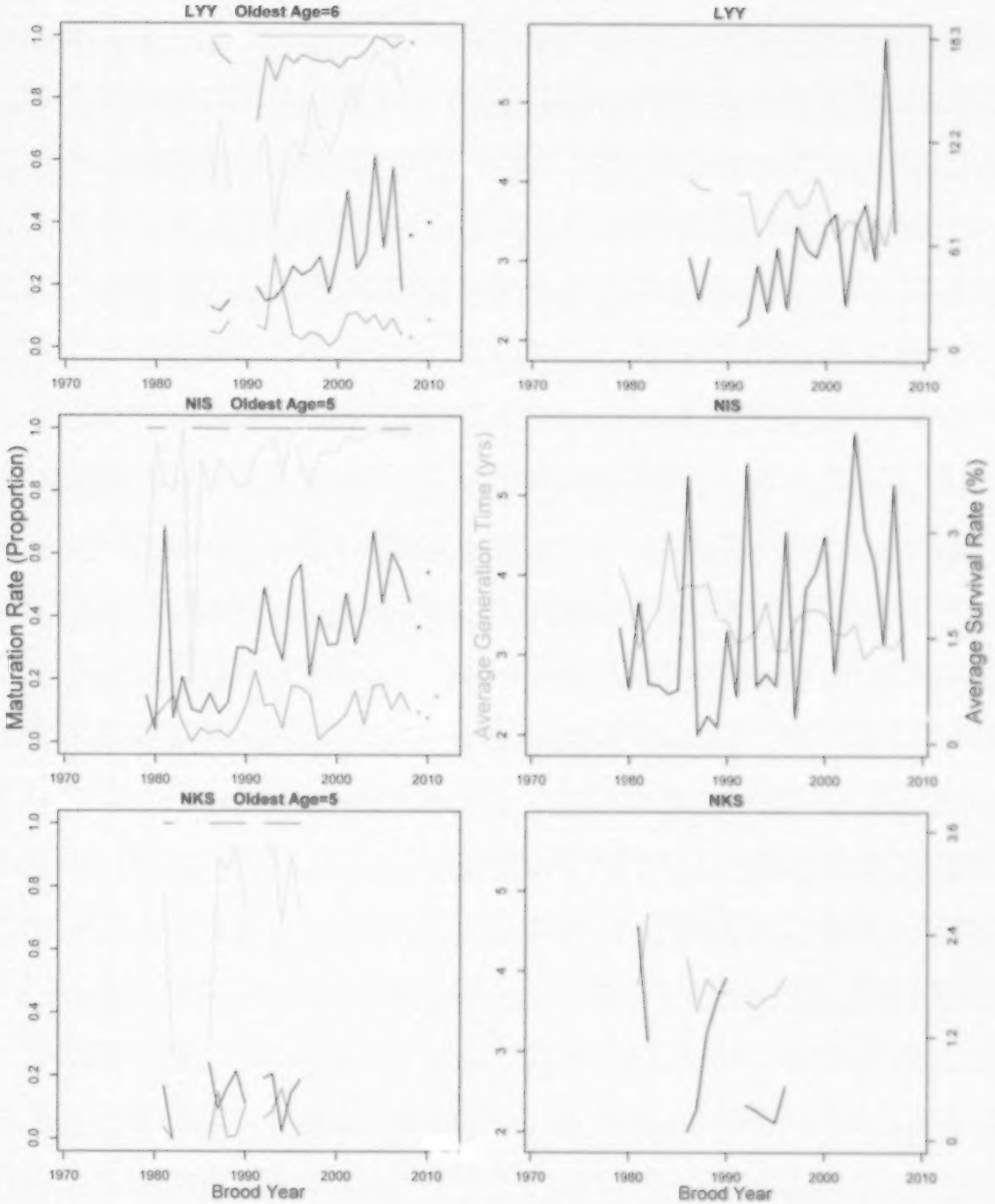

Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year

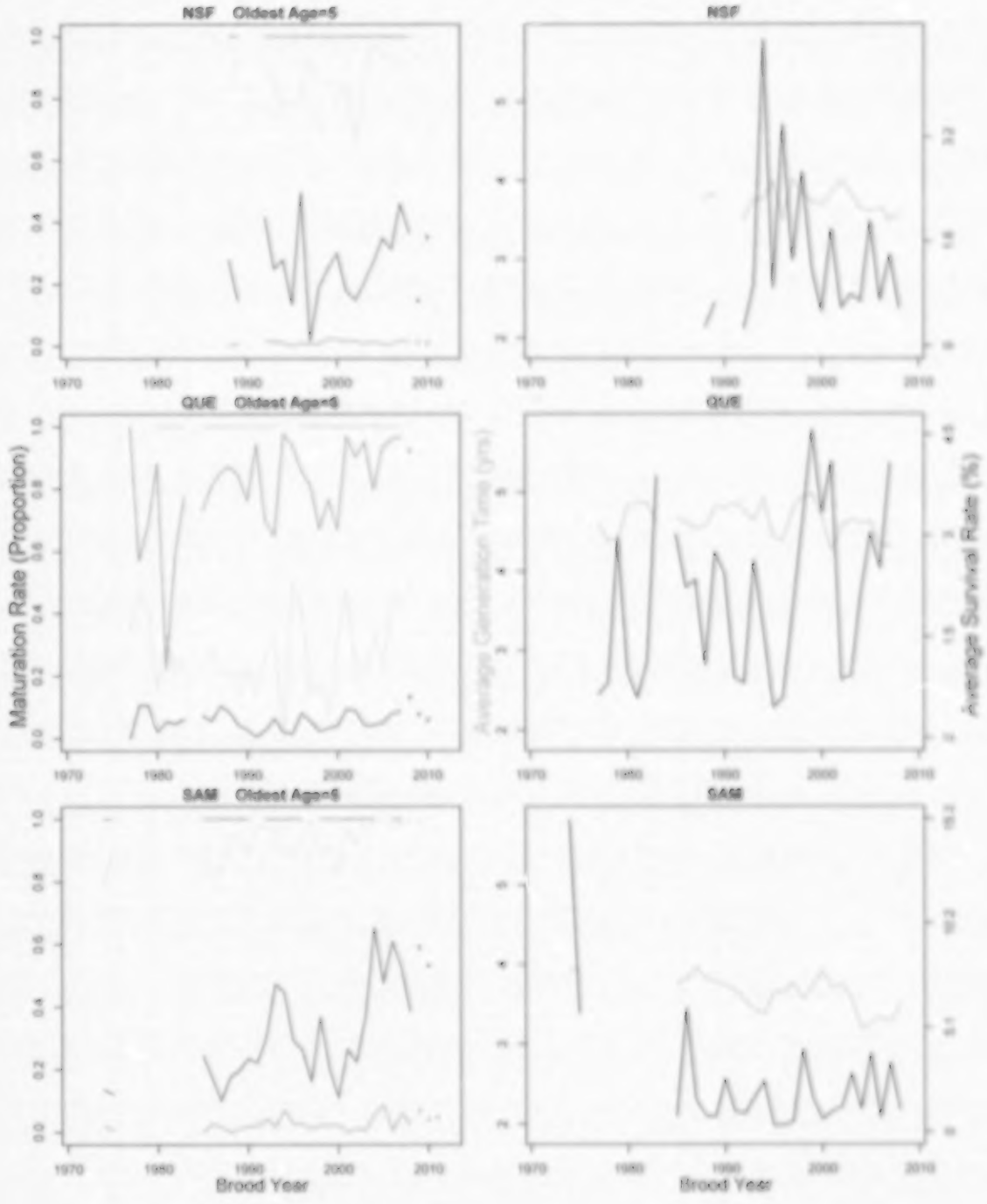

ALP Oldest Age=6
ALP
ANB Oldest Age=6
ANB
CHK Oldest Age=6
CHK
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year

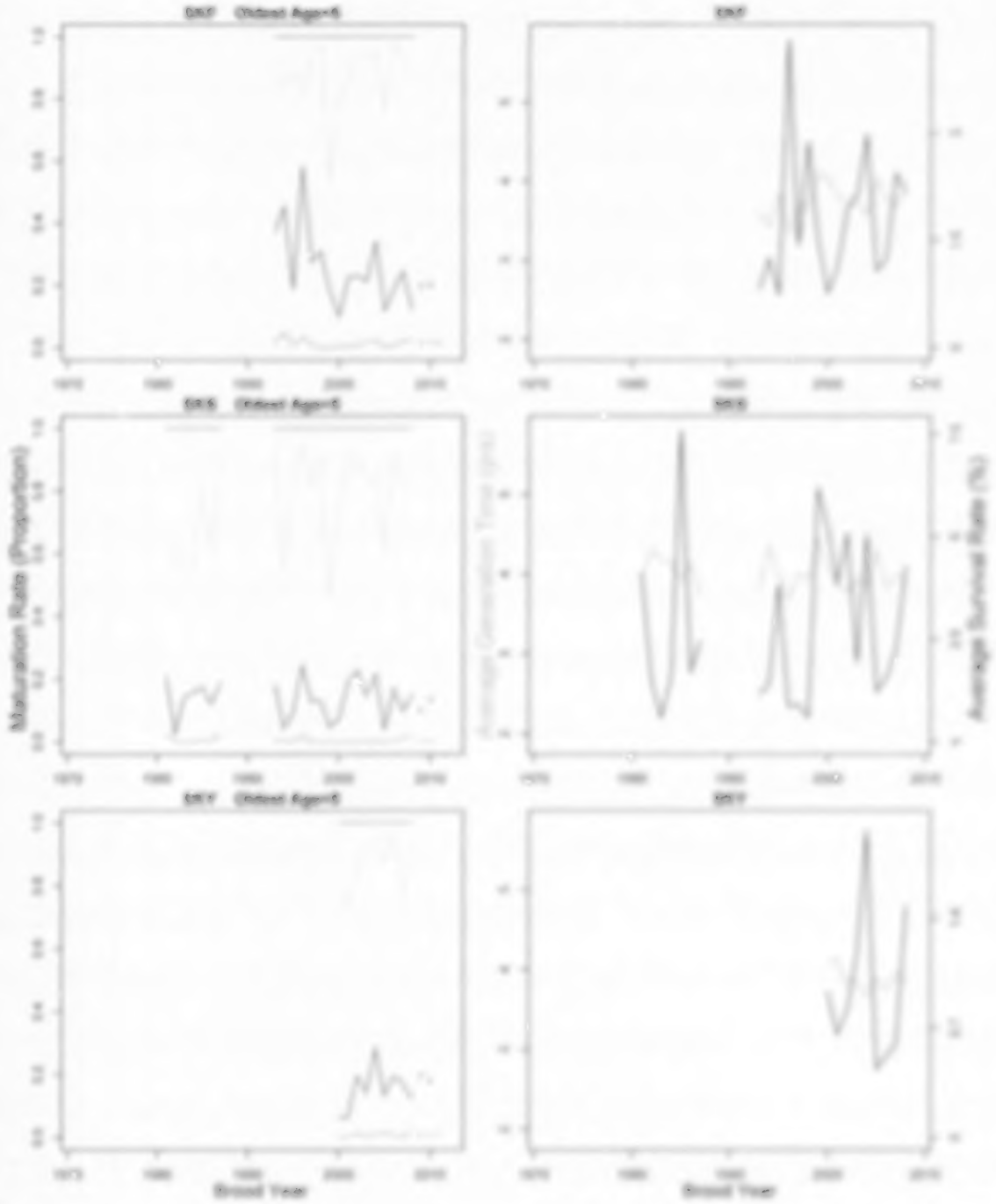

CWF Oldest Age=5
CWF
ELK Oldest Age=5
ELK
ELW Oldest Age=5
ELW
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year

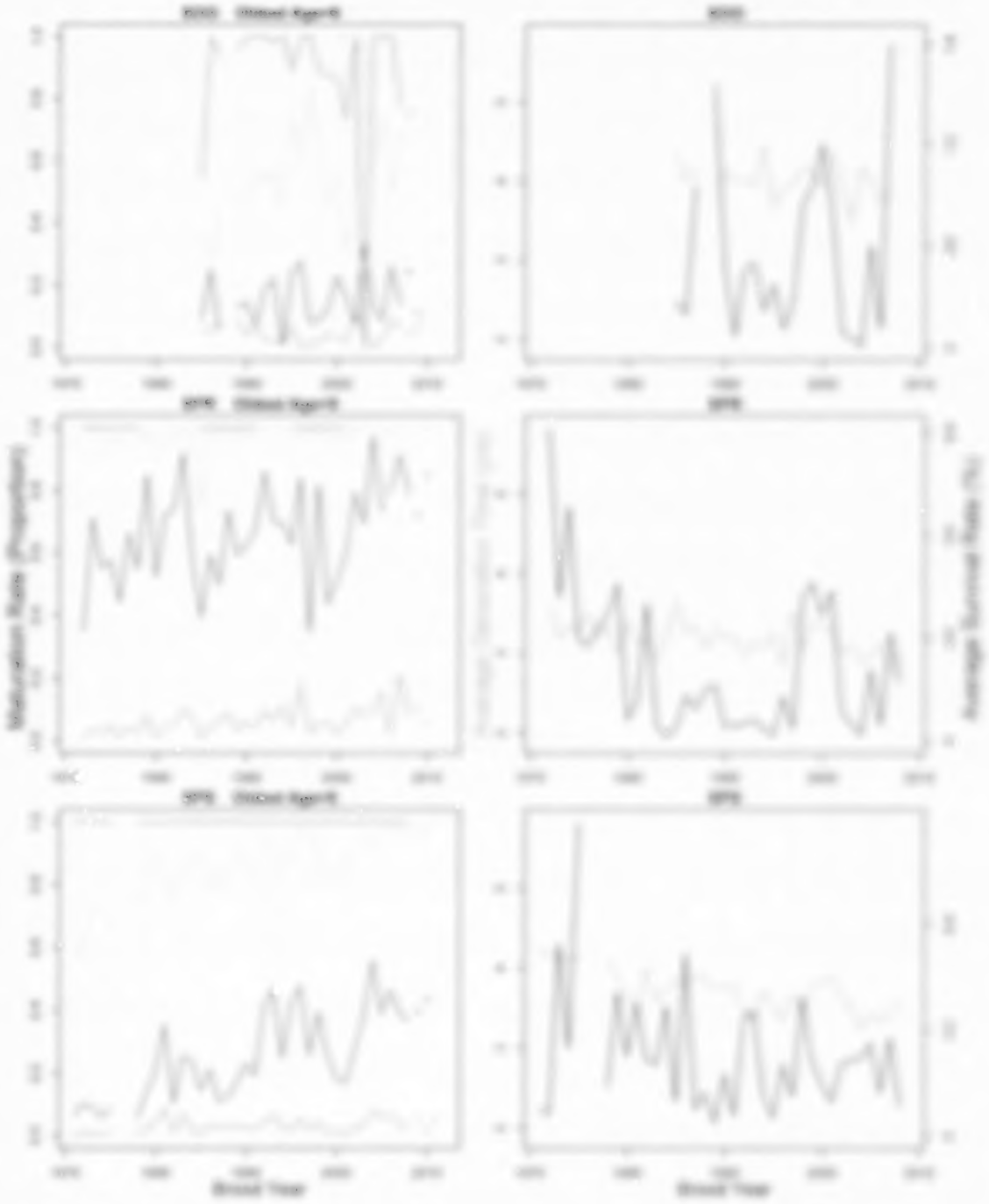

GAD Oldest Age=5
GAD
HAN Oldest Age=5
HAN
HOK Oldest Age=6
HOK
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year

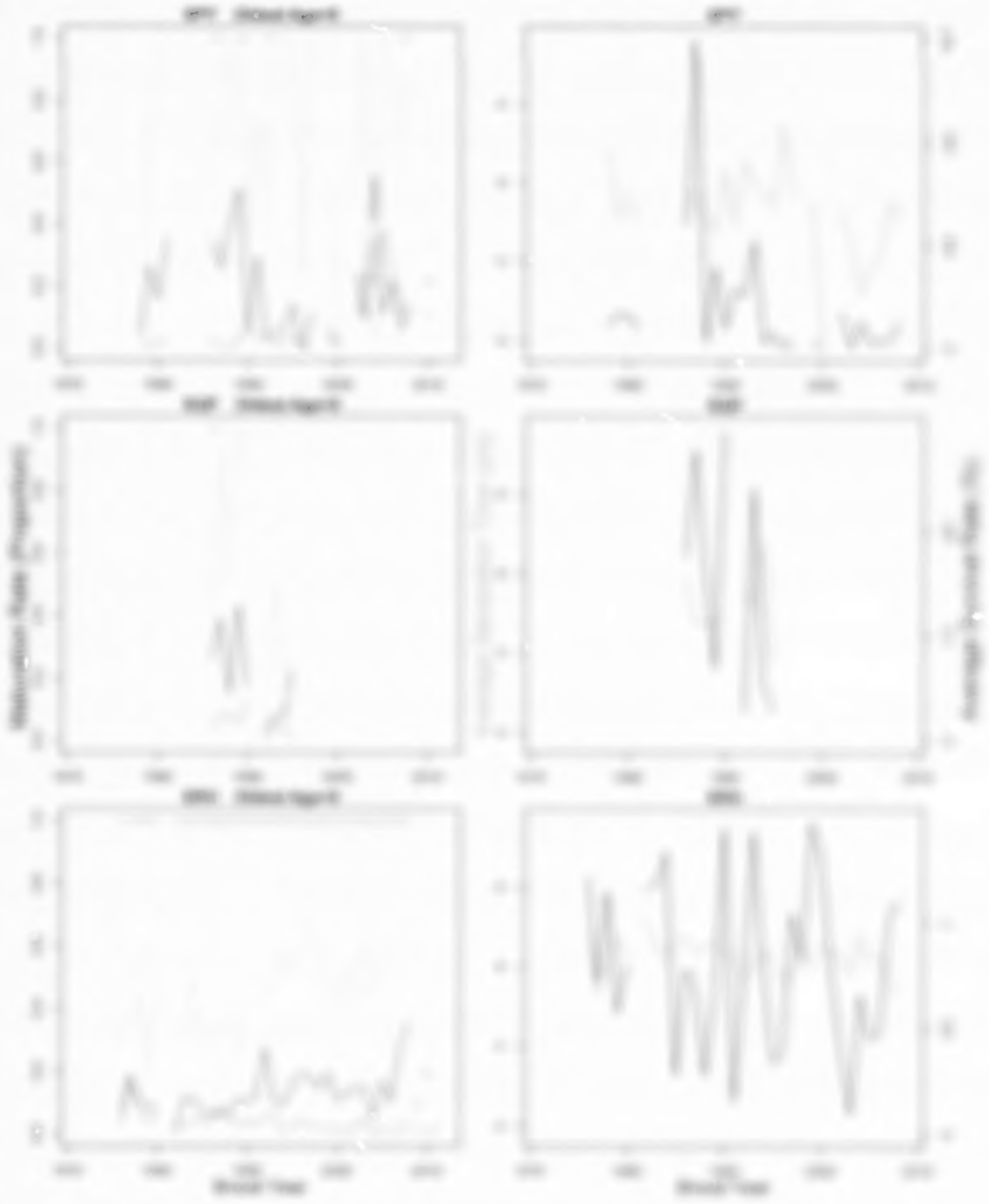

LRH Oldest Age=5
LRH
LRW Oldest Age=5
LRW
LYF Oldest Age=5
LYF
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year

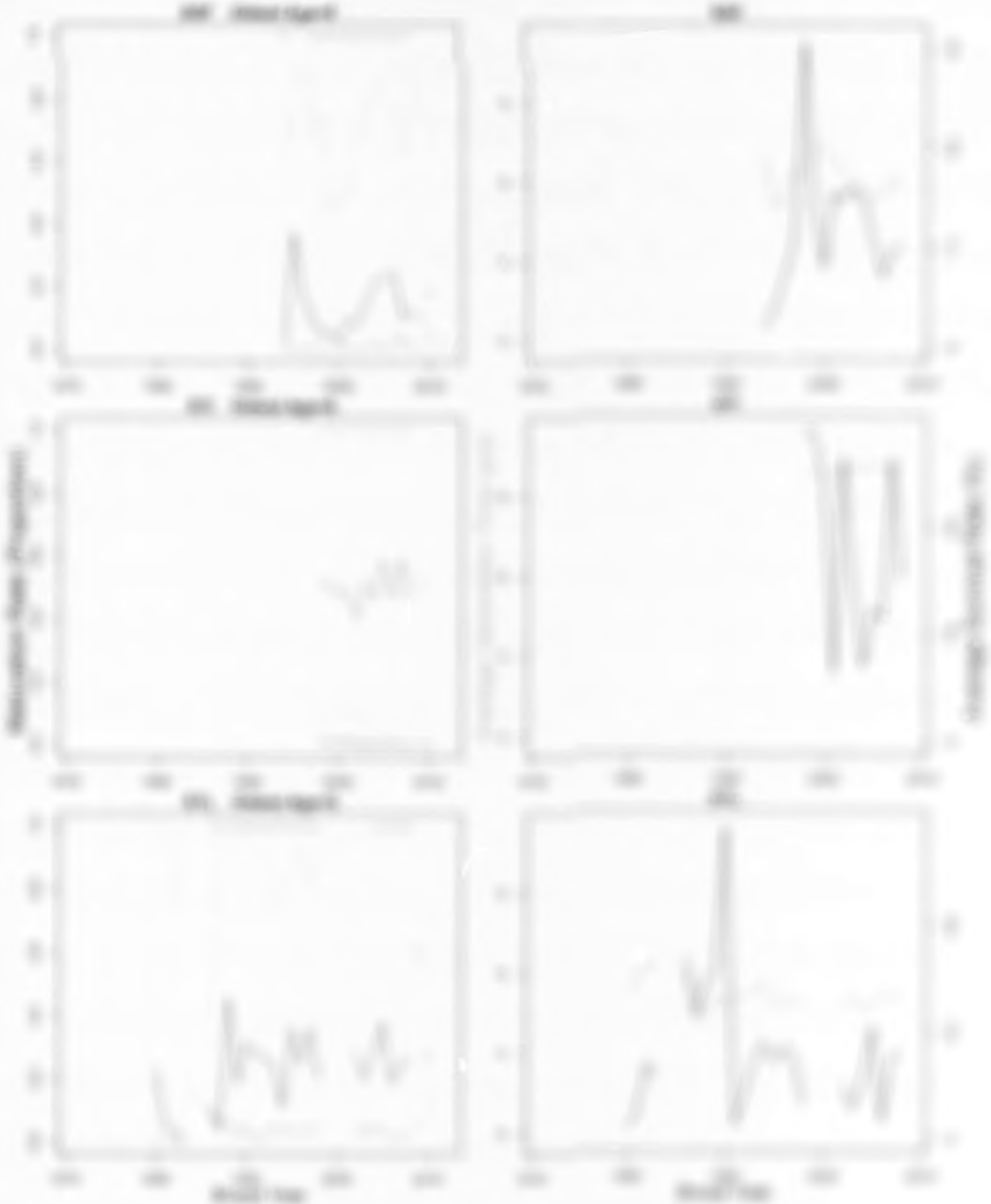

LYY Oldest Age=6
LYY
NIS Oldest Age=5
NIS
NKS Oldest Age=5
NKS
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year

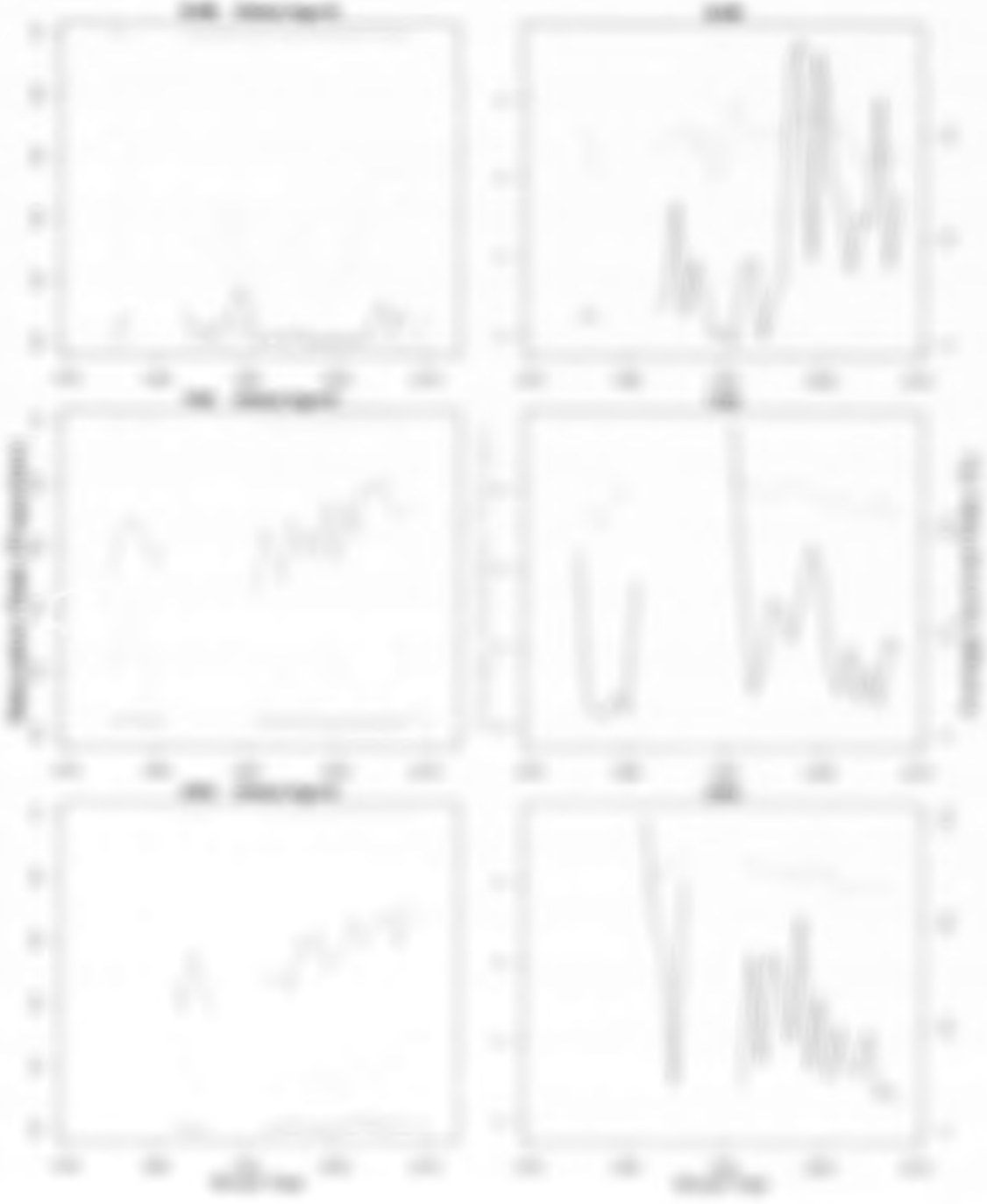

NSF Oldest Age=5
NSF
QUE Oldest Age=6
QUE
SAM Oldest Age=6
SAM
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year

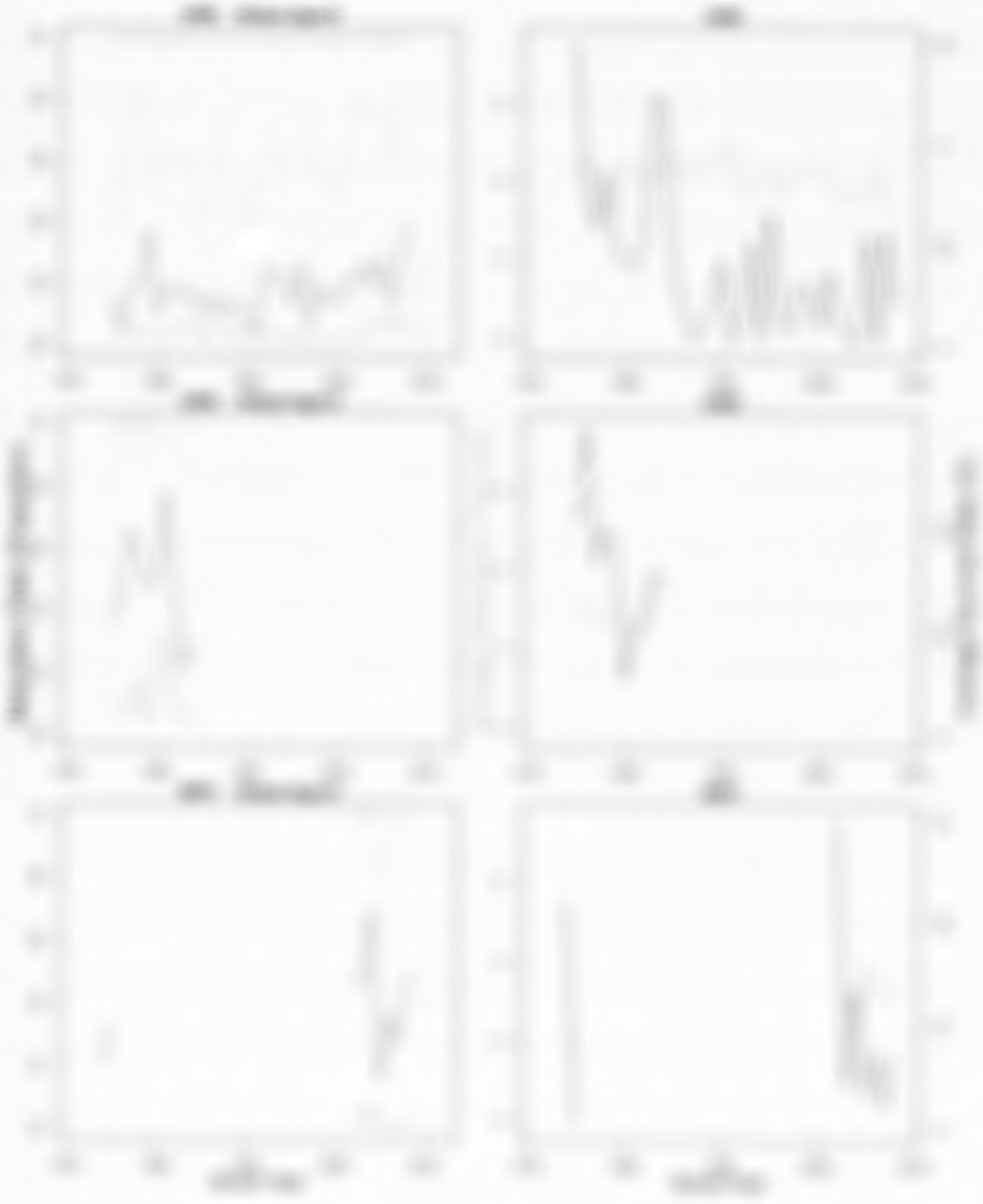

Maturation Rate (Proportion)
Average Survival Rate (%)
Brood Year
Brood Year




Extinction Rate Proportion
Average Turnover Rate (%)
Model Year







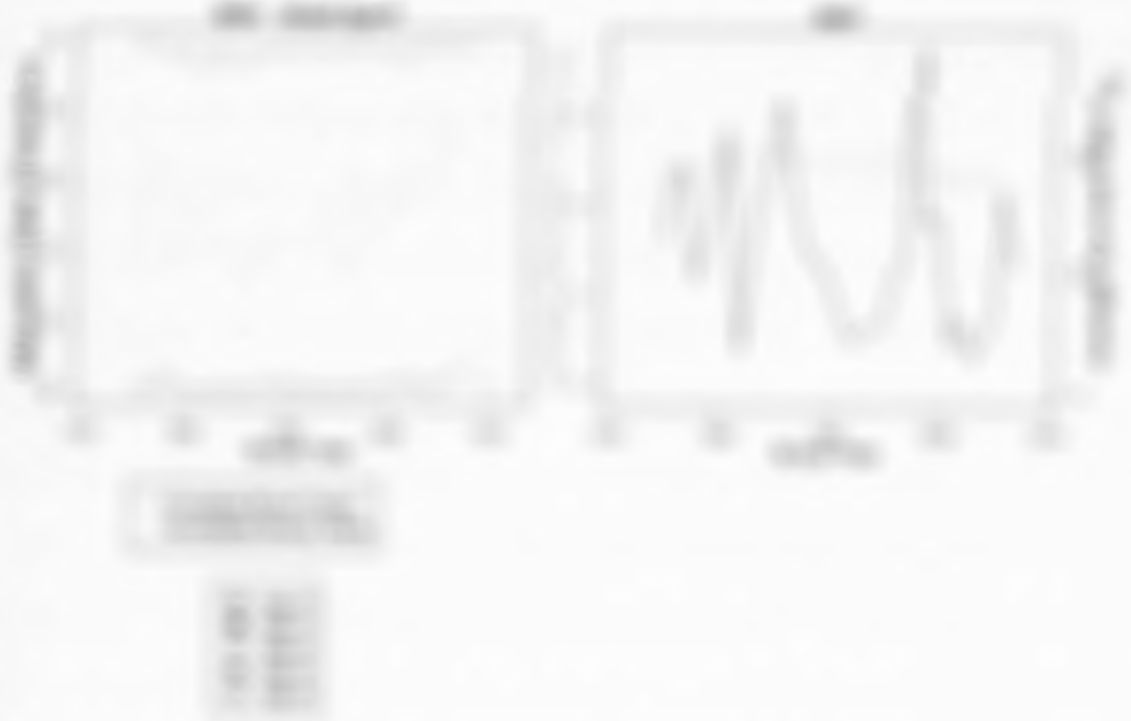


Table B.1. The table below provides a stock name and other information for each CWT indicator stock identified using its three-letter acronym in the graphs above. The stock acronym is highlighted in bold type for those stocks which currently annually provide MR data for Chinook Model stocks included in the SHARCQ file.

CWT Indicator	Stock Name	Jurisdiction	Region	First Age	Final Age
AKC	Alaska Central Inside	AK	SEAK	3	6
AKMF	Alaska Deer Mountain	AK	SEAK	3	6
AKHC	Alaska Herring Cove	AK	SEAK	3	6
AKS	Alaska Spring	AK	SEAK	3	6
ALP	Little Port Walter	AK	SEAK	3	6
AKNR	Alaska Neets Bay	AK	SEAK	3	6
ATSu	Atnarko River Summer	BC	CBC	2	6
ATSp	Atnarko River Spring	BC	CBC	2	6
BCQF	Big Qualicum River Fall	BC	ECVI	2	5
CHF	Chilliwack River Fall	BC	LFR	2	5
CHK	Chilkat Spring	AK	SEAK	3	6
COWF	Cowichan River Fall	BC	ECVI	2	5
CRFF	Cowlitz Fall Tule	CR	LCOLR	2	5
DERF	Dome Creek Spring	BC	UFR	3	6
ELR	Elk River	OR	ORCST	2	5
ELWF	Elwha Fall Fingerling	WA	JFUCA	2	5
GRFJ	George Adams Fall Fingerling	WA	HOODC	2	5
HAWR	Hanford Wild	CR	UCOLR	2	5
HARF	Harrison River Fall	BC	LFR	2	5
HOKF	Hoko Fall Fingerling	WA	JFUCA	2	6
KLSW	Klaskish River Summer	BC	NBC	3	6
KLSY	Klaskish River Yearling	BC	NBC	3	6
LRFH	Columbia Lower River Hatchery	CR	LCOLR	2	5
LRFW	Lewis River Wild	CR	LCOLR	2	5
LYF	Lyons Ferry	CR	UCOLR	2	5
LYFY	Lyons Ferry Yearling	CR	UCOLR	3	6
NAKR	Nanaimo River Fall	BC	ECVI	2	5
NHC	Nicola River Spring	BC	MFR	2	5
NIFJ	Nisqually Fall Fingerling	WA	SPGSD	2	5
NWY	Nooksack Spring Yearling	WA	NPGSD	2	5
NKSF	Nooksack Spring Fingerling	WA	NPGSD	2	5
PRFS	Puntledge River Summer	BC	ECVI	2	5
QUIF	Quinsam Fall Fingerling	WA	WACST	2	6
QUIR	Quinsam River Fall	BC	ECVI	2	6
RBFF	Robertson Creek Fall	BC	WCVI	2	5
SAMF	Samish Fall Fingerling	WA	NPGSD	2	5
SHSU	Lower Shuswap River Summer	BC	MFR	2	5
SKF	Skagit Spring Fingerling	WA	NPGSD	2	5
SKY	Skagit Spring Yearling	WA	NPGSD	2	5
SKF	Skykomish Fall Fingerling	WA	NPGSD	2	5

SOO	Sooes Fall Fingerling	WA	WACST	2	6
SPR	Spring Creek Tule	CR	MCOLR	2	5
SPS	South Puget Sound Fall Fingerling	WA	SPGSD	2	5
SPY	South Puget Sound Fall Yearling	WA	SPGSD	2	5
SQP	Squaxin Pens Fall Yearling	WA	SPGSD	2	5
SRH	Salmon River	OR	ORCST	2	6
SSF	Skagit Summer Fingerling	WA	NPGSD	2	5
STI	Stikine Spring	TBR	TBR	3	6
STL	Stillaguamish Summer Fingerling	WA	NPGSD	2	5
SUM	Columbia Summers	CR	UCOLR	2	5
TAK	Taku Spring	TBR	TBR	3	6
UNU	Unuk Spring	SEAK	SEAK	3	6
URB	Upriver Brights	CR	UCOLR	2	5
UWA	University of Washington Accelerated	WA	SPGSD	2	5
WRY	White River Spring Yearling	WA	SPGSD	2	5
WSH	Willamette Spring	CR	LCOLR	3	6

Appendix C. Description of the MATAEQ Program

In order to produce the MATAEQ file that contains the yearly MR values for the twelve stocks with adequate CWT information and the MR averages computed from these values, a Microsoft VB.NET program (MATAEQVB_xxx.EXE) is used to extract the MR and Adult Equivalent (AEQ) values from the ERA output (OUT) files of the twelve stocks. The VB.NET program also reads the base period MR and AEQ values from the STK file (containing base period stock and age specific cohort sizes, MRs, AEQs, and exploitation rates by fishery) of the Chinook Model. The VB.NET program then calculates the average MR and AEQ values to be used for the years being projected.

Occasionally, MR and AEQ values are missing for certain stocks and broods due to lack of CWT releases and/or recoveries for those broods. In addition, some broods have CWT data but due to inadequate CWT recoveries the MR and AEQ values cannot be reliably estimated. Typically these values are readily detected as outliers relative to MRs calculated by the cohort analysis procedure. In these situations where the CWT recovery data are inadequate, the MR and AEQ values that are read from the OUT files are excluded and treated as though they were missing. The stocks and broods where the MR and AEQ values exist but are set to missing are identified in the table below:

Table C.1. The stocks and broods where the MR and AEQ values exist but are set to missing.

Model Stock	Acronym	ERA Indicator	Excluded Broods[1]
Alaska Spring	AKS	AKS	1976
Lower Bonneville Hatchery	BON	LRH	1977, 1980, 1983, 1986, 1988, 1990-1994, 1996
Cowlitz Fall Hatchery	CWF	CWF	1994, 1997
Lower Georgia Strait Hatchery	GSH	BQR	1992
Lewis River Wild	LRW	LRW	1996, 1997
Oregon Coastal	ORC	SRH	1976
WCVI Hatchery	RBH	RBH	1992, 1997
WCVI Wild	RBT	RBH	1992, 1997
Willamette Spring Hatchery	WSH	WSH	1982, 1994

[1] Excluded broods experienced such poor survival that CWT recoveries were so few that MRs were nonsensical, and the long-term average was used.

In addition, the MR values read from the OUT files for the CHI CWT indicator stock (associated with the Fraser Late Model stock) are replaced with values supplied by Canadian Department of Fisheries and Oceans staff. The replacement values have been adjusted to take into account the differing maturation schedules between the hatchery and wild components of the Fraser Late stock. The resulting AEQ values are then calculated from the user supplied MR values.

The VB.NET program then produces a year, stock and age specific MATAEQ_xxx.DAT file containing the MR and AEQ values that are read into the PSC Chinook Model during the calibration and projection runs. The base period years in the MATAEQ_xxx.DAT file contain the base period MR and AEQ values from the STK file. Years after the base period but prior to the projection years that have valid (non-missing) MR and AEQ values contain data from the ERA OUT files (with the exception of Fraser Late). Years that have missing CWT data (or have been set to missing) contain LTA MR and AEQ values calculated for each stock and age. The projection years contain the average MR and AEQ values calculated for each stock and age based on a specified number of completed broods. For all Chinook Model calibrations prior to 2013, the MRs are based on the average of all available completed broods (except missing or excluded broods). Starting in 2013, the MRs are based on the average of the five most recent complete broods. The average could consist of less than five broods if the five-brood 'window 'also included missing or excluded broods.

Appendix D. Details of Model Evaluation Criteria

D.1 Mean Squared Error (MSE):

MSE provides a measure of the variability of the retrospective forecast errors. It is the average of each of the individual squared errors, i.e., the difference between the model estimated AI and some measure of the true AI, calculated as,

$$MSE = \frac{\sum_{i=1}^{n}(\widehat{AI}_i - AI_i)^2}{n},$$

where $\widehat{AI}_i$ is the estimated AI for year *i* using a particular MR estimate and AI_i is the "true" value of the abundance index for year *i*. It is a measure that includes both the variability of errors, and the bias in AI estimates.

Each of the individual square errors, i.e., $\left(\widehat{AI}_i - AI_i\right)^2$, contributes a proportion of the error to the total. Because the errors are squared, large errors can contribute more to the proportion than smaller errors. Hence large errors can unduly influence the overall MSE and will grow as the total error is concentrated within a decreasing number of increasingly large individual errors. The effect of different MRs on the MSE of model estimates of the AI are shown graphically.

D.2 Median Error

The median error is calculated as,

$$Med.\,Error = median\left(\widehat{AI}_i - AI_i\right), \forall\, i.$$

Medians, like means, are a measure of central tendency. However, unlike averages, or means, it is not influenced by large values. Positive values of the median error will result when AIs tend to be overestimated, negative when AIs are underestimated. Thus, it provides a little more information on overall model behavior than the MSE. Median errors for different estimates of the MR based on different metrics of the true AI are shown graphically.

D.3 Mean Absolute Scaled Error (MASE)

MASE was proposed by Hyndman and Koehler (2006) as a generally applicable, scale-free measure of forecast accuracy. This measure never gives infinite or undefined values. MASE is computed as the average of the absolute values of the scaled retrospective estimation errors. The scaling of the errors involves dividing the errors by the Mean Absolute Error (MAE) computed from the retrospective estimation errors associated with the naïve model based on the MRs for the previous year. A value of MASE less than 1 suggests that the retrospective estimation accuracy of MRs is better than the retrospective estimation accuracy of the benchmark naïve model based on the MRs for the previous year. A value of MASE greater than 1 suggests that the retrospective estimation accuracy is worse than the retrospective estimation accuracy of the benchmark naïve model based on MRs for the previous year.

MASE measures the magnitude of the error compared to the magnitude of the error of a naive one-step ahead forecast as a ratio. A naïve estimate assumes that whatever the MR value was last year it will be the same value this current year. Ideally, the value of MASE will be significantly less than 1. For example, a MASE of 0.5 means that the MR estimate is likely to have half as much error as a naïve estimate. Since MASE is a normalized statistic that is defined for all data values and weighs errors evenly, it is an excellent metric for comparing the quality of different estimation methods.

The advantage of MASE over the more common Mean Absolute Percent Error (MAPE) metric is that MASE is defined for time series that contain zero, whereas MAPE is not. Also, MASE weights errors equally, whereas MAPE weights positive and/or extreme errors more heavily.

D.4 Mean Percent Error

The Mean Percent Error (MPE) takes into account values of the AI, and scales the error accordingly. MPE is calculated as,

$$MPE = \frac{\sum_{i=1}^{n} \frac{(\widehat{AI}_i - AI_i)}{AI_i}}{n}.$$

Because the MPE is not calculated from absolute errors, values indicated by what percentage the AI will be over or under estimated.

Appendix E. Percent Error for Three MR Estimates (3YA, 9YA and ETS) Relative to the Observed MR at Age for Model Stocks in the MATAEQ File for the 2004-2010 Chinook Model Calibrations.

All contributing broods were complete through to the 2010 calibration for each of the Chinook Model stocks based on using observed MRs from the CTC-AWG's exploitation rate analysis in March 2015. Positive values indicate that the forecasted MR exceeded the observed MR at age. Negative values indicate the forecasted MR was below the observed MR. Cases where the observed MR was 0 and percent error could not be calculated are indicated with a horizontal bar ('—'). The first, second and third age are stock-dependent and are defined in the caption for Appendix A.

			First Age			Second Age			Third Age		
CLB Year	Stock #	Stock	3YA	9YA	ETS	3YA	9YA	ETS	3YA	9YA	ETS
2004	1	AKS	139.7	93.6	147.4	-54.1	-71.7	-66.7	-2.7	-18.5	-13.1
2005	1		51.4	32.7	-7.5	-12.5	-48.4	-43.0	-0.2	-19.8	-16.9
2006	1		-34.0	-32.5	-27.4	-16.3	-42.3	-39.6	-3.4	-17.7	-18.3
2007	1		-42.9	-47.5	-41.1	-31.9	-44.8	-45.7	2.2	-9.6	-11.0
2008	1		50.0	31.4	67.8	-22.7	-49.8	-35.5	-23.0	-19.9	-23.4
2009	1		-63.0	-65.1	-10.9	-32.0	-52.2	-44.9	-11.7	-18.2	-15.7
2010	1		19.0	67.0	-1.0	-7.0	-31.9	-27.6	-13.1	-18.7	-17.4
2004	2	BON	9.8	82.3	22.3	123.7	138.6	167.8	10.4	10.9	7.8
2005	2		-51.6	-28.1	-34.0	-17.9	-13.6	0.0	1.0	1.8	-0.8
2006	2		-61.6	-49.9	-61.1	-3.9	1.5	3.8	28.0	28.7	21.8
2007	2		-73.2	-65.9	-70.5	-51.2	-47.7	-48.3	-4.9	-3.8	-4.4
2008	2		-69.0	-47.9	-47.9	-48.8	-30.1	-31.9	-5.6	-3.6	-4.4
2009	2		-53.6	-15.1	-29.2	-53.6	-42.9	-39.6	-9.8	-2.8	-1.2
2010	2		-77.6	-77.6	-74.5	-42.9	-42.2	-39.4	-9.8	-5.9	-4.9
2004	3	CWF	13.3	165.9	-44.4	91.3	86.4	61.1	64.8	67.2	60.2
2005	3		-63.5	-1.2	-85.9	29.5	22.7	28.8	-14.3	-4.0	-9.7
2006	3		-81.6	-76.5	-93.6	-40.8	-29.9	-39.8	-6.0	3.6	-2.5
2007	3		-61.6	-71.4	-57.3	-51.1	-48.9	-44.9	-23.6	-17.6	-18.5
2008	3		-77.5	-79.1	-90.6	-35.4	-9.3	-29.0	-29.9	-24.8	-25.0
2009	3		-69.0	-48.5	-65.0	-38.0	-34.8	-38.7	-21.4	-17.6	-17.2
2010	3		-65.9	-59.7	-68.4	58.9	61.9	60.5	19.1	9.1	8.0
2004	4	GSH	-68.1	-56.9	-64.1	-0.7	33.8	9.4	-8.7	0.8	-4.0
2005	4		-18.0	2.8	-15.4	-20.1	-10.9	-20.9	10.5	13.1	15.9
2006	4		306.9	429.4	321.6	-26.3	-11.4	-22.7	-16.1	-17.2	-19.8
2007	4		-65.5	-61.5	-66.0	-37.9	-36.7	-42.9	0.8	-1.3	-2.3
2008	4		-33.6	-18.7	-24.5	-24.3	-15.8	-24.6	-20.6	-18.0	-20.5

2009	4		-25.1	-43.1	-25.3	-20.4	-21.6	-22.3	-10.7	-15.7	-12.0
2010	4		29.9	5.5	35.0	-24.8	-30.9	-28.7	-6.0	-10.4	-10.2
2004	5	LRW	14.6	117.2	65.0	-11.2	-16.5	-9.3	9.4	-41.9	-30.6
2005	5		-66.9	-7.5	-0.9	-20.2	196.6	258.9	102.6	80.4	103.7
2006	5		-21.2	147.7	225.0	-73.2	19.9	52.1	-49.2	-28.2	-29.6
2007	5		--	--	--	-62.5	34.5	9.9	41.5	41.5	80.2
2008	5		-53.5	30.4	56.2	39.3	94.2	110.2	-47.4	-41.3	-44.0
2009	5		--	--	--	21.5	59.2	-05.6	29.9	2.2	2.6
2010	5		79.1	24.1	123.6	133.8	47.6	118.6	-28.8	-25.5	-24.2
2004	6	ORC	91.3	71.8	161.3	22.0	13.2	-7.1	24.5	8.4	9.3
2005	6		-15.6	-24.2	-23.5	4.2	-0.7	-19.7	7.2	-9.7	-11.7
2006	6		1274.1	1351.9	1748.1	-3.0	5.8	-6.3	22.9	19.0	10.0
2007	6		136.7	155.1	138.8	186.1	201.1	167.9	-22.0	-15.6	-24.2
2008	6		-4.8	112.7	-76.2	-15.8	-13.2	-18.4	3.6	15.4	3.7
2009	6		61.9	86.1	149.3	7.6	35.3	23.4	-20.9	-7.1	-19.9
2010	6		-26.1	-24.6	84.2	-57.2	-47.0	-54.6	-27.0	-16.2	-28.6
2004	7	RBH	48.8	48.0	51.2	-47.8	-46.3	-47.8	-2.0	-7.1	-11.9
2005	7		106.9	184.5	106.9	90.4	59.2	41.5	-3.4	-8.1	-14.2
2006	7		-27.6	0.6	-46.5	-24.1	-19.0	-26.5	-30.8	-14.8	-18.4
2007	7		-52.5	-46.3	-60.3	28.4	32.4	15.9	-3.7	1.0	-4.9
2008	7		-61.1	-57.9	-70.6	-37.4	-37.8	-48.1	-3.3	3.4	-3.4
2009	7		19.4	21.4	10.7	56.4	33.6	23.6	-13.1	-20.2	-25.4
2010	7		-54.4	-52.0	-62.6	25.5	9.8	-2.3	-2.1	-8.0	-13.9
2004	8	RBT	48.8	48.0	51.2	-47.8	-46.3	-47.8	-2.0	-7.1	-11.9
2005	8		106.9	184.5	106.9	90.4	59.2	41.5	-3.4	-8.1	-14.2
2006	8		-27.6	0.6	-46.5	-24.1	-19.0	-26.5	-30.8	-14.8	-18.4
2007	8		-52.5	-46.3	-60.3	28.4	32.4	15.9	-3.7	1.0	-4.9
2008	8		-61.1	-57.9	-70.6	-37.4	-37.8	-48.1	-3.3	3.4	-3.4
2009	8		19.4	21.4	10.7	56.4	33.6	23.6	-13.1	-20.2	-25.4
2010	8		-54.4	-52.0	-62.6	25.5	9.8	-2.3	-2.1	-8.0	-13.9
2004	9	SPR	-33.0	-44.7	-29.6	5.4	12.6	8.9	0.9	1.8	0.1
2005	9		-0.5	-25.7	-13.4	-16.9	-13.4	-17.6	2.4	2.6	0.9
2006	9		-60.1	-35.9	-16.8	-23.6	-4.3	-7.7	-2.1	-1.4	-3.0
2007	9		-72.4	-61.3	-68.7	-38.9	-32.5	-34.0	-2.3	-1.7	-3.1
2008	9		166.8	206.4	156.7	-29.2	-15.2	-13.3	-3.6	-2.2	-3.1
2009	9		-68.4	-70.2	-63.2	-22.1	-22.3	-21.0	-2.4	-1.2	-2.1
2010	9		-8.5	-27.6	-9.2	-23.9	-30.9	-29.4	-1.3	-2.1	-3.1
2004	10	URB	-39.0	-26.8	-20.3	-19.9	-23.1	-24.0	52.8	27.2	25.8
2005	10		-30.4	-20.6	-14.2	-1.8	-14.3	-18.3	29.0	13.2	8.2
2006	10		-81.5	-69.9	-68.3	-45.1	-12.8	-38.7	-20.9	-22.1	-26.6

20007	10		-77.3	-68.2	-65.7	-56.4	-2.6	-14.7	-26.2	-14.3	-21.5
20008	10		-83.4	-81.6	-79.8	-67.4	-25.3	-42.4	-28.5	-16.0	-21.8
20009	10		-98.2	-88.1	-61.0	-26.9	-25.7	-14.0	-20.7	-17.8	-24.1
20010	10		-75.4	-74.2	-72.6	-14.0	-65.4	-27.2	-24.3	-31.2	-7.6
20004	11	WSH	-85.1	-63.4	-12.7	-56.3	-28.3	-28.1	-5.3	-5.1	-5.5
20005	11		-88.7	-71.5	-73.6	-3.6	-12.9	-8.0	-1.5	-1.8	-5.0
20006	11		-41.0	-10.3	-5.1	-25.2	-65.8	-31.4	-8.7	-2.7	-2.7
20007	11		-3.5	-5.3	-5.9	-9.8	-28.2	-22.1	-1.1	-5.9	-5.2
20008	11		-25.7	-56.1	-26.1	-16.4	-24.4	-23.5	-1.6	-2.1	-3.0
20009	11		-58.7	-78.1	-70.8	-17.0	-22.9	-23.4	-5.3	-1.7	-2.5
20010	11		-51.2	-77.7	-71.8	-21.2	-47.1	-68.8	-2.4	-1.1	-1.6
20004	12	FBL	-28.0	-93.3	-29.2	-20.0	-26.8	-34.0	-11.8	-19.3	-1.1
20005	12		-11.1	-86.2	-65.8	-1.9	-19.6	-27.0	-8.6	-6.4	-8.7
20006	12		-83.9	-85.4	-85.1	-63.0	-54.7	-70.9	-9.3	-8.0	-15.9
20007	12		-80.7	-55.1	-55.1	-63.3	-50.1	-54.7	-12.7	-8.8	-8.7
20008	12		-25.9	-80.0	-80.6	-62.1	-68.9	-25.2	-5.8	-2.6	-5.0
20009	12		-56.8	-56.6	-55.5	-19.8	-20.0	-28.4	-7.5	-5.3	-12.4
20010	12		-10.7	-12.7	-80.1	-62.0	-68.6	-34.9	-5.6	-6.2	-2.5

Note that Percent Error (PE) for a stock, age, calibration year and estimate type is calculated as:

$$PE = \left(\frac{(Estimate - Observed)}{Observed}\right) * 100\%$$

Appendix F. Mean Percent Error (MPE) of Three WR Estimates (IRA, IRA and OTC) Relative to the Observed WR at Each of Three Ages for Chinook Model Stocks in the MAFISS File.

Means are based on percent errors calculated by stock and age for calibration years 1998–2016 and are based directly on data in Appendix E. The statistical summary was limited to this set of calibrations because all observed WRs are from completed broods. Observed values were obtained from the results of the CTC AWG's March 2019 cohort analysis procedure applied to CWT indicator stocks associated to the Chinook Model stocks in the MAFISS.xls file. Positive values indicate that the MPE exceeded the actual WR at age. Negative values indicate the MPEs were below the actual WR at age. The first, second and third age are stock dependent and are defined in the caption for Appendix A.

		First Age			Second Age			Third Age		
Stock #	Stock	IRA	IRA	OTC	IRA	IRA	OTC	IRA	IRA	OTC
1	ANYC	17.2	11.4	38.2	25.2	48.7	84.3	7.4	27.4	58.4
2	BOW	11.8	28.8	81.1	13.3	5.2	1.8	1.2	7.8	1.8
3	CMT	148.8	48.1	71.1	1.1	6.8	8.3	1.8	1.1	8.7
4	COO	38.1	38.8	23.8	23.8	13.8	23.8	7.1	7.8	7.8
5	DNR	8.8	81.8	58.8	1.8	82.1	88.7	8.1	1.8	8.1
6	DRC	218.8	267.8	53.8.8	25.8	27.8	11.1	1.7	8.8	8.8
7	KBH	25.8	18.8	28.1	23.1	8.8	8.1	8.8	7.7	23.1
8	RBT	25.8	18.8	28.1	23.1	8.8	8.1	8.8	7.7	23.1
9	UPR	18.8	8.8	8.1	21.1	23.1	38.1	1.1	8.8	1.8
10	UNS	48.7	58.1	58.1	58.8	38.1	23.1	1.8	1.8	7.1
11	WVH	48.7	48.1	48.8	28.8	23.1	23.1	8.1	8.1	8.7
12	YRL	48.1	48.1	58.8	13.1	13.8	13.8	1.1	1.8	1.8
Grand MPE		1.1	11.9	11.8	8.1	8.1	9.8	3.1	5.8	9.1

Note that Mean Percent Error for a stock at age and forecast method is calculated as:

$$MPE = \frac{\sum_{k=1}^{NumCalibrations} \left(\frac{Estimated - Observed}{Observed} \right)_k}{NumCalibrations} \times 100\%$$

NumCalibrations in the above formula equals 7 at each age for all stocks except the first age for LRW. The observed value for the first age was zero in two years (2007 and 2008; see Appendix C) and thus MPE could not be calculated.

The sample size and denominator for the Grand MPE = 7 calibrations x 12 stocks = 84.

Appendix A: Squared Error for Three-Mill Estimates (3M), 870 and 1773 Relative to the Observed Mill-at-Age for Model Stocks in the Mill Mill Age for the 2000–2010 Brood Model calibrations.

All contributing brood-years complete through to the 2016 Brood Model calibration for each of the Model stocks based on using observed Mills from the exploitation rate analysis conducted by the CTC 2000 to March 2015. The first, second and third age are stock dependent and are defined in the options for Appendix A.

			First Age			Second Age			Third Age		
Cal. Year	Stock #	Stock	3M	870	1773	3M	870	1773	3M	870	1773
2004											
2005											
2006											
2007											
2008											
2009											
2010											
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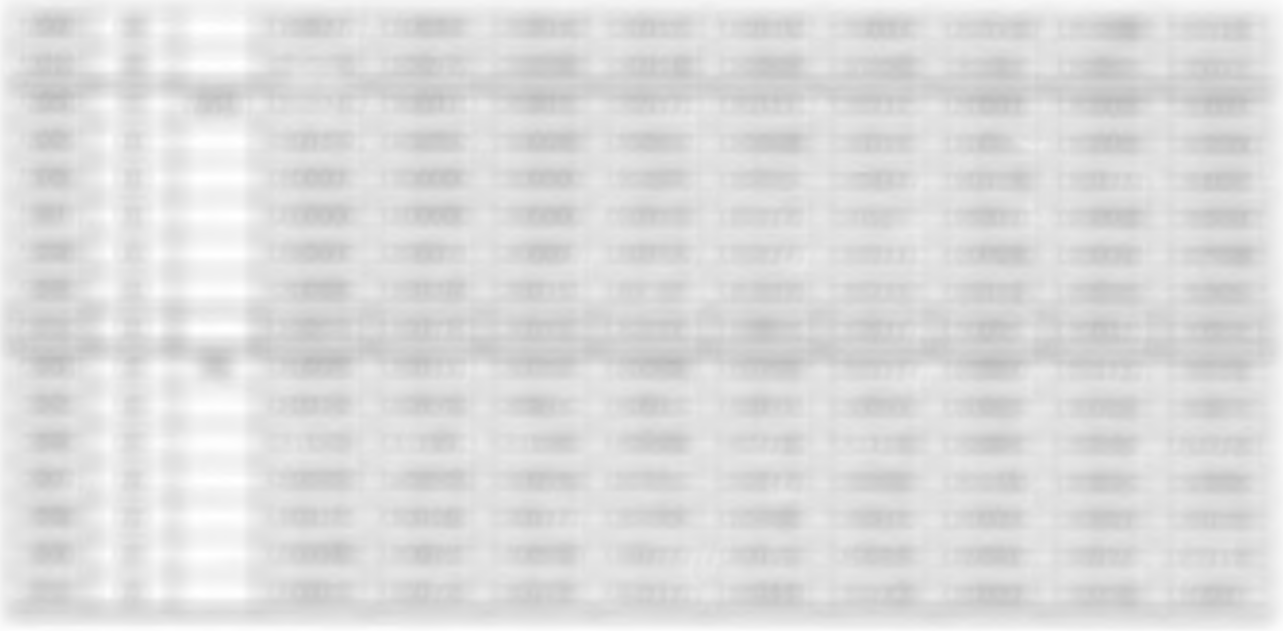

Appendix I. Preseason (Pre) to First Postseason (Post 1) Squared Error (SQE) and Percent Error (PE) Calculated for Each AABM Fishery and Calibration Years 2008-2013 for All MR Estimation models.

[redacted]

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2008	1.46	1.61	0.0169	-9.2%	1.57	1.63	0.0036	-3.7%	0.87	0.93	0.0036	-6.5%
2009	1.79	1.86	0.0068	-6.5%	1.66	1.59	0.0049	-8.2%	0.83	0.86	0.0036	-7.0%
2010	1.62	1.68	0.0036	-3.8%	1.45	1.45	0.0000	0.0%	0.75	0.68	0.0049	10.2%
2011	1.36	1.30	0.0676	20.0%	1.30	1.07	0.0529	21.5%	0.67	0.58	0.0081	15.5%
2012	1.08	0.99	0.0081	9.5%	0.93	0.90	0.0009	3.2%	0.62	0.63	0.0001	-30.1%
2013	1.23	1.12	0.0100	8.9%	1.06	1.01	0.0009	3.0%	0.69	0.59	0.0092	16.4%
2014	1.36	1.38	0.0009	-2.5%	1.06	1.15	0.0081	-7.8%	0.87	0.88	0.0001	-1.1%
2015	1.66	1.67	0.0001	-0.7%	1.21	1.30	0.0121	-9.6%	0.95	0.82	0.0169	15.5%
2016	1.26	1.22	0.0036	3.5%	1.18	1.13	0.0025	6.6%	0.73	0.71	0.0004	2.8%
2017	1.25	1.66	0.1681	-24.7%	1.15	1.53	0.1444	-24.8%	0.78	1.06	0.0784	-26.4%

[redacted]

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2008	1.73	1.93	0.0400	-10.5%	1.56	1.73	0.0289	-7.1%	0.85	0.90	0.0025	-5.6%
2009	1.87	1.81	0.0036	3.3%	1.56	1.56	0.0000	0.0%	0.81	0.82	0.0001	-1.2%
2010	1.56	1.61	0.0025	-3.1%	1.39	1.43	0.0016	-1.4%	0.70	0.67	0.0009	6.5%
2011	1.46	1.27	0.0361	15.1%	1.26	1.05	0.0441	18.1%	0.63	0.57	0.0036	10.5%
2012	1.00	0.96	0.0016	4.2%	0.90	0.90	0.0000	0.0%	0.77	0.63	0.0196	22.2%
2013	1.23	1.16	0.0049	6.0%	1.03	1.03	0.0000	0.0%	0.69	0.62	0.0064	10.8%
2014	1.23	1.23	0.0000	0.0%	1.11	1.17	0.0036	-5.1%	0.97	0.91	0.0036	6.4%
2015	1.52	1.50	0.0004	1.3%	1.30	1.32	0.0004	-1.5%	1.06	0.86	0.0400	23.8%
2016	1.30	1.21	0.0081	7.4%	1.20	1.12	0.0064	7.1%	0.77	0.71	0.0036	8.5%
2017	1.22	1.67	0.2025	-26.9%	1.13	1.55	0.1764	-27.1%	0.78	1.05	0.0729	-25.7%

7YA MRs

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2004	1.72	1.88	0.0237	-8.2%	1.57	1.67	0.0114	-6.4%	0.84	0.93	0.0076	-9.4%
2005	1.83	1.79	0.0014	2.1%	1.50	1.55	0.0023	-3.1%	0.79	0.81	0.0003	-2.1%
2006	1.56	1.65	0.0083	-5.5%	1.38	1.43	0.0018	-2.9%	0.68	0.67	0.0001	1.7%
2007	1.53	1.27	0.0713	21.1%	1.27	1.04	0.0541	22.4%	0.63	0.56	0.0052	13.0%
2008	0.99	0.95	0.0018	4.5%	0.88	0.88	0.0000	-0.4%	0.73	0.63	0.0106	16.5%
2009	1.21	1.16	0.0031	4.8%	1.02	1.03	0.0002	-1.4%	0.68	0.62	0.0043	10.6%
2010	1.22	1.24	0.0005	-1.8%	1.10	1.18	0.0065	-6.8%	0.96	0.93	0.0012	3.7%
2011	1.55	1.54	0.0001	0.6%	1.31	1.35	0.0014	-2.7%	1.08	0.90	0.0333	20.4%
2012	1.38	1.24	0.0185	10.9%	1.25	1.14	0.0120	9.6%	0.83	0.73	0.0096	13.4%
2013	1.27	1.69	0.1716	-24.5%	1.17	1.57	0.1560	-25.2%	0.82	1.07	0.0602	-23.0%

8YA MRs

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2004	1.77	1.92	0.0218	-7.7%	1.60	1.70	0.0095	-5.7%	0.86	0.94	0.0068	-8.8%
2005	1.89	1.79	0.0104	5.7%	1.53	1.54	0.0000	0.0%	0.81	0.80	0.0000	0.6%
2006	1.55	1.63	0.0073	-5.2%	1.36	1.41	0.0026	-3.6%	0.67	0.66	0.0001	1.7%
2007	1.51	1.28	0.0553	18.4%	1.26	1.05	0.0450	20.2%	0.62	0.56	0.0034	10.4%
2008	1.00	0.96	0.0019	4.6%	0.89	0.89	0.0000	-0.2%	0.73	0.63	0.0107	16.5%
2009	1.23	1.15	0.0062	6.9%	1.03	1.02	0.0000	0.5%	0.68	0.61	0.0052	11.9%
2010	1.20	1.24	0.0014	-3.0%	1.08	1.18	0.0090	-8.1%	0.93	0.93	0.0000	-0.3%
2011	1.55	1.54	0.0003	1.0%	1.31	1.35	0.0013	-2.6%	1.10	0.89	0.0416	22.9%
2012	1.38	1.25	0.0159	10.1%	1.25	1.14	0.0118	9.5%	0.82	0.74	0.0067	11.1%
2013	1.29	1.71	0.1789	-24.7%	1.18	1.59	0.1690	-25.9%	0.84	1.08	0.0592	-22.5%

9YA MRs

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2004	1.81	1.90	0.0081	-4.7%	1.63	1.70	0.0040	-3.7%	0.87	0.94	0.0057	-8.0%
2005	1.87	1.81	0.0033	3.2%	1.54	1.55	0.0001	-0.7%	0.81	0.81	0.0001	0.9%
2006	1.58	1.62	0.0020	-2.7%	1.39	1.41	0.0003	-1.3%	0.68	0.66	0.0006	3.6%
2007	1.51	1.27	0.0572	18.9%	1.25	1.04	0.0421	19.7%	0.61	0.55	0.0033	10.4%
2008	0.99	0.96	0.0009	3.2%	0.88	0.89	0.0001	-1.3%	0.72	0.63	0.0080	14.3%
2009	1.23	1.16	0.0059	6.6%	1.03	1.03	0.0000	0.2%	0.68	0.61	0.0050	11.5%
2010	1.22	1.23	0.0001	-0.9%	1.09	1.17	0.0056	-6.4%	0.93	0.92	0.0001	1.0%
2011	1.53	1.54	0.0001	-0.5%	1.29	1.35	0.0030	-4.1%	1.07	0.90	0.0301	19.3%
2012	1.38	1.26	0.0135	9.2%	1.25	1.15	0.0104	8.9%	0.84	0.74	0.0088	12.6%
2013	1.30	1.72	0.1774	-24.4%	1.18	1.59	0.1680	-25.7%	0.84	1.10	0.0635	-23.0%

10YA MRs

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2004	1.84	1.99	0.0219	-7.5%	1.66	1.75	0.0083	-5.2%	0.88	0.95	0.0058	-8.0%
2005	1.99	1.83	0.0241	8.5%	1.60	1.57	0.0012	2.2%	0.83	0.81	0.0005	2.8%
2006	1.61	1.64	0.0011	-2.1%	1.41	1.42	0.0001	-0.6%	0.69	0.66	0.0007	4.0%
2007	1.53	1.26	0.0715	21.2%	1.26	1.04	0.0512	21.8%	0.62	0.55	0.0042	11.7%
2008	0.99	0.96	0.0011	3.4%	0.87	0.89	0.0001	-1.4%	0.71	0.62	0.0079	14.3%
2009	1.22	1.16	0.0034	5.0%	1.02	1.03	0.0002	-1.3%	0.67	0.61	0.0037	10.0%
2010	1.23	1.24	0.0001	-0.7%	1.10	1.17	0.0053	-6.2%	0.93	0.92	0.0001	0.9%
2011	1.55	1.53	0.0004	1.2%	1.30	1.34	0.0012	-2.6%	1.08	0.89	0.0343	20.7%
2012	1.36	1.26	0.0108	8.3%	1.23	1.14	0.0082	7.9%	0.83	0.75	0.0069	11.1%
2013	1.30	1.73	0.1856	-24.8%	1.18	1.60	0.1759	-26.1%	0.85	1.10	0.0607	-22.4%

11YA MRs

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2004	1.85	2.00	0.0241	-7.8%	1.67	1.77	0.0086	-5.2%	0.89	0.96	0.0049	-7.3%
2005	2.01	1.86	0.0246	8.4%	1.63	1.59	0.0014	2.4%	0.85	0.82	0.0008	3.5%
2006	1.64	1.67	0.0005	-1.3%	1.44	1.43	0.0000	0.2%	0.69	0.66	0.0010	4.7%
2007	1.56	1.28	0.0786	22.0%	1.28	1.05	0.0551	22.4%	0.62	0.56	0.0044	12.0%
2008	1.00	0.96	0.0022	4.9%	0.88	0.89	0.0000	-0.2%	0.72	0.62	0.0093	15.5%
2009	1.22	1.16	0.0039	5.4%	1.01	1.03	0.0001	-1.1%	0.67	0.61	0.0037	10.0%
2010	1.22	1.25	0.0006	-2.0%	1.09	1.18	0.0074	-7.3%	0.92	0.92	0.0000	-0.5%
2011	1.56	1.54	0.0004	1.3%	1.31	1.34	0.0010	-2.4%	1.08	0.90	0.0333	20.3%
2012	1.38	1.24	0.0171	10.5%	1.24	1.13	0.0123	9.8%	0.83	0.74	0.0078	11.9%
2013	1.29	1.74	0.2048	-26.0%	1.17	1.60	0.1910	-27.2%	0.85	1.11	0.0661	-23.3%

LTA MRs

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2004	1.89	2.06	0.0289	-8.3%	1.72	1.82	0.0100	-5.5%	0.93	0.99	0.0036	-6.1%
2005	2.08	1.90	0.0324	9.5%	1.70	1.64	0.0036	3.7%	0.90	0.84	0.0036	7.1%
2006	1.70	1.73	0.0009	-1.7%	1.51	1.50	0.0001	0.7%	0.74	0.69	0.0025	7.2%
2007	1.64	1.34	0.0900	22.4%	1.36	1.09	0.0729	24.8%	0.67	0.57	0.0100	17.5%
2008	1.06	1.00	0.0036	6.0%	0.94	0.92	0.0004	2.2%	0.76	0.64	0.0144	18.8%
2009	1.30	1.20	0.0100	8.3%	1.07	1.06	0.0001	0.9%	0.71	0.63	0.0064	12.7%
2010	1.31	1.30	0.0001	0.8%	1.16	1.23	0.0049	-5.7%	1.00	0.95	0.0025	5.3%
2011	1.68	1.62	0.0036	3.7%	1.40	1.41	0.0001	-0.7%	1.15	0.90	0.0625	27.8%
2012	1.51	1.32	0.0361	14.4%	1.35	1.20	0.0225	12.5%	0.90	0.77	0.0169	16.9%
2013	1.41	1.82	0.1681	-22.5%	1.27	1.68	0.1681	-24.4%	0.91	1.15	0.0576	-20.9%

ETS MRs

	SEAR				NWC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2004	1.85	2.05	0.0384	-9.6%	1.69	1.80	0.0133	-6.4%	0.90	0.96	0.0032	-5.9%
2005	2.02	1.89	0.0182	7.3%	1.65	1.62	0.0009	1.8%	0.82	0.84	0.0006	-3.0%
2006	1.66	1.72	0.0038	-3.6%	1.66	1.68	0.0003	-1.1%	0.75	0.67	0.0058	11.4%
2007	1.59	1.33	0.0714	20.1%	1.31	1.08	0.0535	21.3%	0.64	0.55	0.0070	15.2%
2008	1.03	1.00	0.0010	3.2%	0.91	0.92	0.0000	-0.5%	0.67	0.63	0.0020	7.0%
2009	1.20	1.19	0.0069	7.0%	1.06	1.06	0.0000	0.6%	0.69	0.61	0.0052	11.7%
2010	1.29	1.29	0.0000	-0.1%	1.15	1.21	0.0047	-5.6%	0.91	0.96	(-0.0005	-2.5%
2011	1.62	1.60	0.0004	1.3%	1.36	1.36	0.0006	-1.7%	1.09	0.99	0.0102	20.1%
2012	1.46	1.19	0.0729	22.7%	1.30	1.10	0.0417	18.6%	0.89	0.72	0.0142	16.5%
2013	1.29	1.64	0.1195	-21.1%	1.17	1.52	0.1249	-23.1%	0.83	1.05	0.0506	-21.4%